WEATHER

Practical, Dramatic and
Spectacular Facts About
a Little Studied Subject

by

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and

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WEATHER

Preface

This book was planned not logically, but psychologically. All the authors' acquaintances who could be persuaded to listen, even the casuals of street car or smoking room, were asked what they most felt need of knowing about the weather. Replies were tabulated. So far as possible the queries are answered here. If this book does not tell Americans what weather facts they yearn to know, that is the fault of our long-suffering acquaintances, not of

THE AUTHORS.

Acknowledgments

Portions of Chapters 9 and 26 originally appeared in *The American Weekly*, as did also the diagram of the cause of a mirage on page 193. The authors are indebted to Mr. Morrill Goddard, Editor of that publication, for kind permission to make use of the material here.

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WEATHER

Chapter I

WHY WEATHER EXISTS

THE most remarkable fact about weather is that it exists. The earth is very old and its present state is not the normal one. For a million years or more of the immediate past the planet happens to have been stormy. Rains and winds have been belaboring it; hot spells and cold spells have chased each other across its face; thunder and lightning have been incessant. That is the only kind of world man knows. Man imagines, therefore, that weather is a necessary evil.

It is not. A million years is but a transient fever in the billions of years of earth history. The present chills and spasms of weather are exceptional. For more than nine-tenths of the earth's lifetime there seems to have been no such thing as weather. Every day was the same as every other day and all the years alike.

Scattered through the rocks of the earth's crust geologists find fossils of animals and plants which lived millions of years ago. From these something can be read of the climates of the different eras. There were long ages for which these fossils record pleasant, palm-dotted lands from the equator almost

to the poles. During hundreds of millions of years there is no trace of cold or snow or storms. Gentle rains fell, perhaps, at the same hour each day; pleasant breezes blew; mild changes of temperature came and went with the well-behaved seasons. If the great dinosaurs, who enjoyed their best days during one of these pleasant, weatherless periods, had felt the need of almanacs they could have written down their weather forecasts a thousand years in advance, for the sunshine and showers of those days were dependable enough to be forgotten, as human beings now forget the presence of the air they breathe.

That things are different nowadays is due chiefly to the wrinkles on the earth's face; the wrinkles called mountains and ocean basins and continents. These wrinkles are very tiny in comparison with the size of the whole planet; about in the same proportion as invisible pin scratches on a billiard ball. But they are enough to create vast movements of the thin film of water called the sea and of the slightly thicker film of air called the atmosphere. These movements cause weather.

Almost everything that happens on earth, even life and death, is driven and managed by sunlight. If the sunlight fell on a uniform, world-wide sea it would warm all of it much alike. Living creatures might inhabit it; indeed creatures have lived in such wide-spread seas in the earth's past, but they would be everywhere much the same. Similarly, if the sunlight found only a uniform continent, a single featureless plain covering the entire earth, there would be small diversity either of weather or life. Every part of the plain would be heated and cooled in turn as night succeeded day. Gentle breezes might blow

at times of sunrise and sunset but that would be all. The world's present weather, as different from this as a lively youngster is from a wax doll, is a fact of geography; a consequence of lands and seas.

Whenever, in past earth history, there have been deep seas and lofty continents and massive mountain ranges there also have been storms and cold winters and ice-caps on the poles and all the other vicissitudes of weather. Whenever the earth's countenance has worn the contrary mask of low, flat continents and wide-spread shallow seas, rain and sunshine seem to have displayed a comfortable monotony. The famous reproach that nobody does anything about the weather does not apply to Nature. Every stream that helps to wear down the earth's mountain ranges is doing its best to get rid of weather altogether.

The best model of how the continents make weather is a burning house. The flames go upward in a great column of fire and smoke, not downward to spread out on the ground; a familiar fact but one which holds the chief weather clue. Hot air is lighter than cold air. The fire heats the surrounding air and it rises, just as the old-fashioned hot air balloons used to rise at country fairs carrying aloft the aeronaut and his parachute.

A continent heated by the sun's rays acts like a gigantic fire. It warms the air above it. This air tends to rise. When the continent cools off at night the air above it cools too. Then this air tends to sink, precisely as the hot-air balloon comes down when its filling of heated air has cooled. Similar motions are generated by sunlight in the earth's oceans; the surface water being heated by the sun's

rays in one part of the earth and left cooler in others. Thus are created great rising and falling motions both in the ocean and in the atmosphere; currents which the irregular distribution of the earth's land and water convert into horizontal ocean currents like the Gulf Stream and similar air currents like the trade winds; currents so complicated that scientists have scarcely begun to understand their details.

Cut up some tiny bits of tissue paper and stir them into a teakettle full of cold water. Put the kettle on the stove and heat it. You will see the bits of suspended paper begin to move up and down and around the kettle as the heat sets up a circulation of the water. That is very much what happens when the earth's air is heated by a sun-warmed continent beneath it.

Were it possible to watch the earth from some outside point of vantage as one watches a teakettle, and were balloons scattered through the air to serve as markers of the currents, all the gigantic circulation of the atmosphere could be seen precisely as one sees the water move in a kettle on the stove. But that is denied to man except in imagination. He is like a tiny animalcule creeping on the bottom of the teakettle. Just as that animalcule might watch the floating bits of paper circulating above him, so man watches clouds or test balloons to learn the circulations of the air. Gradually he gathers facts about how this circulation is altered by day or night and by the seasons. That is the basis of the world's increasing weather knowledge, for the fundamental cause of weather changes is the gigantic engine of the boiling atmosphere, driven by the heat of the sun.

To understand the weather of any country or to

predict it what would be needed is perfect knowledge of all these circulations of the air. Unfortunately, that is easier asked for than obtained. A race of intelligent animalcules on the bottom of the teakettle might spend many lifetimes in industrious research without learning all about the currents in the water above them. The earth is even more difficult than the teakettle for the multiplicity of mountains and plains and seas complicates enormously the effects of the sun's heat on the air. Only in a very few places in the world where the air movements are exceptionally simple, like the western coast of India, are the movements of the atmosphere adequately known.

Above the United States, for example, enormous whirling eddies of air, like water eddies in a gigantic whirlpool, move majestically across the country every few days from west to east. They are probably produced by currents of cold air from the polar regions meeting and reacting with warm air heated by the continent. They are the chief cause of American weather changes, for the air currents that mingle on their borders bring most of the rains and cold waves and winter storms. To understand the workings of these giant air eddies is the most important single problem of American weather science, but one still far from being solved.

Elsewhere over the globe other things reflect the workings of the gigantic weather engine; trade winds following so steadfastly their tracks across the ocean, tornadoes swooping down to wreak devastation so unexpectedly that the utmost powers of science can make no guess where one will strike next, glaciers in Switzerland advancing or retreating majestically a

few feet each year in response to cold or warmth or to the snowfall on the peaks of the Alps, typhoons harrying the China Sea to pile up a hundred junks along the shore and drown a thousand of their sailors, two thousand thunderstorms flashing and rumbling away their brief lives somewhere on earth throughout every instant of the day or night. Of all the titanic motion pictures of Nature none is greater than the mighty panorama of the weather.

In all countries and all seasons rain or snow, calm or storm, cold or heat are shuffled and dealt by the power of the sun. The amount of energy which the earth receives each minute is paid back at once into space from the outer layers of the earth's air. Certainly our planet's continual income of sunlight and sun heat is not less than the equivalent of one hundred million tons of coal each minute. While you read this sentence sunlight falling on the earth will bring it as much new heat as though ten million tons of the best coal had burnt to ashes in the same time.

If you happen to be reading this at night the inhabitants of some other continent will be receiving the sunlight, but every continent has its turn. Every breeze that ventures into your window, every raindrop that patters on your roof is a gift from the sun. The gigantic power of hurricanes or tornadoes is but a tiny fraction of this energy from the sun. All this has been going on, geologists believe, for at least a billion years, for there is evidence that sunlight was reaching the earth hundreds of millions of years ago very much as it arrives to-day.

The mere existence of this powerful, atmospheric engine that deals out weather worries the average

man less than the vagaries of it. The machinery does not seem to be running smoothly. One can be reasonably sure when he goes to bed at night that air to breathe will still be there in the morning. Nobody would promise himself such constancy of the weather. Virtually every language has its proverbs in which the weather stands as simile for all that is most fickle. Every one of these proverbs is richly deserved. The whole machine seems vastly erratic and unreasonable.

This is undoubtedly an illusion of size and ignorance. A mosquito riding on a locomotive might find himself assaulted from moment to moment by showers of water or clouds of steam or frightful waves of heat and cold. It all would seem, doubtless, quite wild and meaningless. Even an intelligent mosquito, with brains beyond his proboscis, might be puzzled. A creature about as large as the locomotive is needed to gain some easy glimmerings of what it is all about. The weather engine is too large for men to understand it easily or quickly, but that is no reason to doubt its being understandable. As some of the fast travelling mosquitoes might cling to their locomotive and hold a congress, agreeing to try to learn what manner of thing had hold of them, so man proposes the science of meteorology.

There is probably only one thoroughly satisfactory reason for personal study of any science, which is that one enjoys it. Many people have had this benefit from watching the weather and thinking about it, for no science has a more active and enthusiastic regiment of amateur helpers and observers. But this is a practical age and every science must justify itself as apt to be of some use in the world.

It is probably unfortunate for weather science, at least for its public reputation, that the duty of day by day, country-wide forecasting was wished on it too soon. This is not saying that the weather forecasts now issued in numerous countries are useless, for they are sometimes very valuable indeed. The point is that when some service is rendered regularly by an agency which makes a business of that service, people expect it to be accurate. Especially are mistakes resented when agency and service are labelled with the magic name of science, for however much the scientists themselves protest, people continue to regard science as a kind of benevolent magic which can fail only if the magicians be incompetent.

In simple truth, neither a true weather science nor logical weather forecasting is yet a possibility. We human mosquitoes have not yet studied closely enough or comprehensively enough the gigantic weather engine which sprinkles us and fans us. Present weather forecasts are merely guesses; guesses made, it is true by able men on the basis of knowledge which slowly grows more suitable and complete, but which is still woefully lacking.

To answer the question of why the world has weather is easy. It is because the enormous energy of sunlight sets up vast circulations in the oceans and in the air, which circulations are modified by the continents. To answer the inevitable next question of why a certain city has a certain kind of weather on a certain day is still almost impossible except by making a lucky guess. A grasshopper might be sure that it was an army went over him without being able to pick out each soldier whose foot he felt.

Chapter 2

RAIN AND CLOUDS

WATER falling from the sky in drops is so commonplace a happening that only children and meteorologists ever wonder about it. The sky draws up water. The water falls. That is rain. Rain is commonplace because it seems inevitable.

Yet it takes a complicated and rather spectacular procession of events to bring water from the sky in drops, and rain is not inevitable. There have been times in the long history of earth when, likely enough, it did not rain anywhere for a million years at a time. Such times might happen again.

If the air did not mill about with an upward, boiling sort of motion there would be no rain. If there were no dust in the air there would be no rain.

If it never rained the earth would be a far wetter place than it is. The air would be steam, as it was in rainless ages long ago. The ground would be slime. Every building would drip huge drops, inside and out. Every person would slosh around with his body and clothes wringing wet, as though he had just crawled from a pond. Life would be one long Turkish bath.

For rain takes the humidity, the moisture, out of the air by condensing it into water. Without rain, the moisture of the tremendously humid atmosphere would condense on every solid thing on earth, and bathe it constantly in water.

Because of the heat-using process called evaporation, the air around the earth is full of moisture, like the air over a boiling teakettle. As every one knows who has seen a kettle boil, two things are necessary to change that moist vapor into drops of water. One thing is coolness; the gaseous moisture will not become liquid until it is chilled. The second essential is something for the moisture to condense on. Precisely the same things are necessary to change to rain the moisture in the air around the earth.

The upward boiling motion of the air supplies the coolness. Dust, or dust-like substances in the air provide the something for the moisture to condense on. Both are essential. Without either there would be no rain.

The moisture in the atmosphere comes from the ocean, fundamentally. Sunlight falls on the ocean, heats the surface water and brings about its evaporation into the air, just as the flame heats the teakettle and sends up its water in steam. If the sun heated the ocean as hot as the flame heats the kettle, the sea water too would rise in steam. The water from inland lakes, from rivers, from the moist leaves of plants and from the damp earth also evaporates.

But the water from these inland sources came to them originally from the sea, for the moistened air caused by evaporation of the ocean moves shoreward and provides rain for the continents. Thus there is a cycle of evaporation and condensation; the atmosphere is really a vast steam boiler, into which steam is continually driven by evaporation. If the moisture were not condensed and removed as rain, the atmosphere of the earth would be one huge cloud of steam, like the steam above a teakettle. It would be satu-

rated by moisture. In technical terms, the relative humidity would be one hundred per cent.

So far, in this procession of events which ends in the commonplace happening of rain, the atmosphere has become filled with moisture. The air has drawn up water. What is there to prevent the water remaining in the air? What brings the drawn-up water down again?

Again there are two factors: the motion of the air, and the dust in it.

"Vertical circulation" is what meteorologists call the upward and downward boiling motion of the air, which, because it is the essential cooling agent, is more important in the production of rain than the other factor of dust. The reason why vertical circulation cools air is contained in the scientific law that gas is heated when compressed and cooled when expanded—air, it must be remembered, is a gas.

The savages of Borneo employ this principle very cleverly in a fire-making device. Tinder is put into a hollow stick containing a piston. When the piston is suddenly driven in the compression of the air, and only that compression, heats the air inside the stick and fires the tinder. The air compressed for drilling and riveting machines gets so hot that it would burn the operator if it were not cooled by special devices.

The expansion of air, conversely, cools it quickly. The job of running an air drill in the summer is pleasantly cool because when the compressed air expands through the drilling machine it becomes quite cold.

Modern refrigerating machines use this principle that compression heats gas and expansion cools it. Their operation is merely alternate expansion and

compression. The ammonia gas, in the typical mechanical refrigerator, is compressed by a pump. The heated, compressed gas is then cooled by the water. The cooled, compressed gas is allowed to expand. It becomes very cold. Because it is so cold, it absorbs heat from the contents of the box and thus refrigerates them.

Illustrations like these should suffice to prove the practical working of the law of expansion and compression of gases. Air of the earth's atmosphere, obviously, follows the same law.

But what is there to expand the air of the earth's atmosphere? Expansion assumes previous compression. With nothing in nature to compress it, the air would seem to be in a constant state of expansion and no further expansion would seem possible.

There are essentially three factors which make possible the movement and expansion of air. These are: differences in atmospheric pressure, differences in temperature, and inequalities in the surface of the earth.

Atmospheric pressure decreases with height. Gas-filled balloons expand as they rise and contract as they fall, because the pressure around them decreases with their ascent and increases with their descent. If they were filled tightly with gas on the ground they would burst when they rose to a point where the pressure around them was much less than the pressure inside them.

The air is heated at the surface of the ground in hot weather and rises, like the hot air balloon in the first chapter. Also, there occur mixtures of hot and cold air currents which can bring about the rising motion of the air essential to the production of rain.

When the whirling storms called cyclones progress across the United States from west to east a mixture of warm and cold air currents may occur both in front of the whirling storm and behind it. Then the cold air gets underneath the warmer currents and forces them upward. The heating of air at the surface of the ground produces the cauliflower-like clouds that bring many of the summer rains. The cyclones bring most of the winter rains.

Inequalities in the surface of the earth, such as mountain ranges, provide the third factor in the vertical circulation of the air. More or less constant air currents blow, for example, against the western coast of the United States from the Pacific Ocean. As this relatively warm and moist air from the Pacific is blown against the mountain ranges of the coast the mountains force it to rise. The rise cools the air and rain falls on the Pacific slopes.

Other special circumstances may force the air upward and persuade it to produce rain, but these are the main causes.

A mass of air is lifted by the heat of the ground or by cyclonic currents. As it moves higher it must expand, because the atmospheric pressure is less. As it expands it cools, following the same law as the ammonia gas in the refrigerator. In the rain-making procession water has been drawn up from the sea, air currents have risen, expanded and cooled. The moisture from the sea is about to condense. It must have something on which to condense.

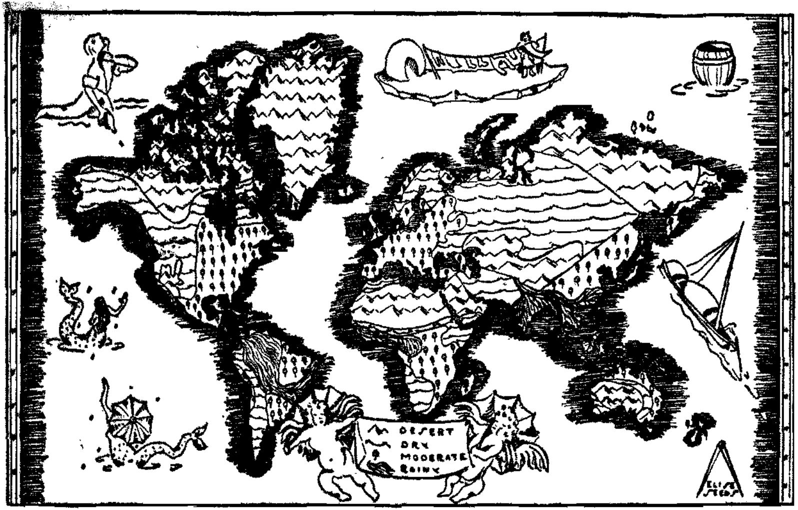
If air were absolutely pure and dust-free it would hold vastly more than the normal amount of water, in vapor form, except where it came in contact with a cool solid substance. Wherever that contact oc-

curred—the walls of the containing vessel, for example—the excess moisture from the supersaturated air would be deposited on the walls, just as it is deposited on the walls of a steam room in a Turkish bath.

Experiments with the moisture in such dust-free air may be carried out in laboratories, where the air can be filtered, but the air about the world is never dust-free. "Dust," in this case, is not quite accurate; it is only a convenient term. The tiny particles in the air which are to provide condensing places for the moisture are not all of them ordinary dust. Many are the far smaller motes technically called ions. An ion is an electrified atom, or a group of electrified atoms.

The atmosphere is filled with these ions, with ordinary dust particles and with other minute things. There may be as many as fifty or a hundred thousand of these particles in a cubic inch of air. And these particles, whether ions, dust, crystals of sea salt, or what-not, are the cores, centers, or nuclei around which the moisture in the air condenses to form droplets of water.

No mere theory or plausible guess is this statement that raindrops begin to be raindrops around these tiny cores of "dust"; it is a fact easy of demonstration in a laboratory, and a fact very convenient in the study of atoms. The tracks of atoms can be made visible, so that they look like the tracks of tracer bullets from a miniature machine gun, because electrified atoms act as centers of condensation for moisture so that their tracks become visible lines of fog. When high speed atoms, such as the helium atoms from radium, are shot through the air they hit against and



HOW WEATHER DEALS OUT DROUTH AND DELUGE TO DIFFERENT PARTS OF THE GLOBE.

The rainiest spot on earth is in India, but Borneo, parts of South America and a spot or two in Africa are not far behind. The Arctic Regions are surprisingly dry; drier than some of the most famous deserts.

electrify thousands of air atoms. If the air which contains these electric centers of condensation is then suddenly cooled, the moisture in it condenses on these nuclei and the track of fog is visible.

About half of the rain-making parade has passed the conventional given point: Water has been drawn up into the air, the air and its moisture have been cooled, condensing centers have been provided.

Very small drops of water are first formed. That is the shape the moisture takes when it condenses around ion or dust cores. The droplets may be as big as one one-hundredth of an inch in diameter or as small as one ten-thousandth of an inch. So small are they and so closely packed together, perhaps several thousands in a cubic inch, that they do not appear as individual drops but as a mist or fog. The mass of air has risen. It has cooled and has condensed its moisture into closely-packed droplets. A cloud has been born!

It is a cloud, this heaping mass of vapor, and not yet a deluge of rain. It floats. And it floats because the droplets of which it is formed are so small that they fall through the air at an almost imperceptible rate—perhaps less than a hundred feet in an hour; so slowly that the upward rise of the air overcomes the momentum of their descent and buoys them up.

The tumbled, fleecy cloud heaps of a summer's day are thus really the tops of rising columns of air. They can be seen boiling into their typical cauliflower shape as the warm air from below rises into their mass, cools, and forms more cloud heaps.

A cloud may be content to remain a cloud. It does not necessarily mean immediate rain. If the air

does not rise too high or get too cold, or if there was not very much moisture in it to begin with, there may be no precipitation—the meteorologist's term for the actual downpour.

The cauliflower-shaped cloud of summer is, of course, only one of many kinds, all of which have been classified. Modern cloud classification is based upon suggestions made by an English chemist, Luke Howard, more than a century ago. To be scientific in those days classifications had to be in Latin, hence Howard called his main forms of cloud "cumulus," "stratus," "cirrus," and "nimbus." His names are still used.

Cumulus, which means heap, is the name for the cauliflower clouds. They are, as has been said, the heads of rising columns of air.

Stratus means sheet or layer. The flat, sheet-like clouds which sometimes makes a veritable ceiling across the sky are stratus clouds. The general rise of a layer of air, lifted bodily like a blanket until it cools in a more or less horizontal plane, produces such clouds.

Cirrus is the Latin name for a curl and is applied to the lacy bits of cloud which usually form high in the air. They are caused chiefly by whirls or eddies in the air, in the centers of which centrifugal force rarifies the air and cools it into clouds. When these air eddies are bent, as frequently happens, the cloud lines are also bent and curled.

Somewhat akin both to cirrus clouds and to cumulus clouds are the finger-like clouds which sometimes stretch across the sky like the stripes on a fish—the so-called "mackerel sky." Such clouds also are caused by air eddies. When the centers of these

eddies lie horizontal, like a series of ripples on water, clouds form along these centers in stripes or ripples of similar shape.

Luke Howard's fourth cloud class, the nimbus, means rain cloud; the dark heavy cloud of a summer storm. Like the cumulus cloud, the nimbus is usually a part of a rising column of air, but it has gone much further on its way toward making rain.

So many combinations of circumstances may produce clouds that there are innumerable variations on Howard's simple classifications. More than one hundred types of cloud have been identified, like new species of fauna or flora, by various meteorologists. There is, in fact, an international cloud atlas, and the weather experts of the world are now preparing a new edition. For practical purposes, however, there is little importance in detailing the differences between one sub-type of cloud and another. Howard's classification is enough.

Clouds are really a valuable indication of what is going on from one moment to another in different parts of the air. In olden days, ship captains and other weatherwise and weather-anxious persons spent a lot of time observing cloud formation and movement. They had to, because there was practically no other way of predicting changes in weather. With the coming of practicable barometers, thermometers, and all the other implements of modern weather science, the study of clouds has been relatively neglected. As a result, much less is now known than formerly about forecasting the weather for small definite areas and over short spaces of time. Long-range and world-wide weather prognostica-

tion has advanced enormously, but the man who can tell whether it will rain where he is standing inside of a few hours has become a rare bird.

Clouds differ in lightness or darkness according to the progress made by their droplets on the road to rain. When the particles of water are so small that they reflect the light as so many crystals would, the cloud is white. When the water particles have become larger—so much larger that they reach the raindrop class—these drops begin to absorb the light instead of reflecting it. That makes the cloud dark. A very dark cloud is already raining; a white cloud, in the Indian's phrase, is "rain—not yet."

Now the procession of rain making has almost reached the place where it is to disband. Moisture has been drawn up into the sky, air has risen and expanded and cooled, the moisture has condensed into tiny drops around the dust and ions, clouds of these droplets have heaped together.

But no rain has fallen. The drops of condensed moisture are still nowhere near the size of raindrops. What makes them grow larger?

Rain itself was long a mystery. There was no apparent way in which the very small drops could combine to form larger drops. But recently a distinguished meteorologist, Dr. W. J. Humphreys of the United States Weather Bureau, has worked out the details of a plausible theory of rain. This theory may be stated as a paradox:

Rain must rise before it falls!

When the rising air mass cools enough to condense some of its moisture on ions and other nuclei to form clouds, these nuclei have fulfilled their function. Other nuclei of condensation are not instantly at

hand for the rest of the moisture to condense on. But the air partly converted into cloud continues to rise. It grows still colder. More water must be condensed.

On what? There must be some rallying point, some core or nucleus.

Obviously, this additional condensation will take place on the drops of water already formed. Droplets in a cloud which continues to rise will grow in size as more moisture gathers around them. That is the modern theory of the formation of raindrops.

A cloud that does not rise far enough produces no rain. It must rain upward before it can rain down. But in the cloud that rises farther and farther, the water drops grow larger and larger, until they are heavy enough to fall. They start downward as rain, but the end is not yet. In falling they may pass through a mass of rising cloud which has not yet reached its own time for rainmaking. The procession is countermarching on itself. Smaller, rising water drops are encountered and are swept out of the newer line of march to join their older and larger brethren which have begun to fall. The faster the large drops fall, the more small drops they pick up. The larger they get, the faster they fall.

This is the precipitation of rain in the language of the weather bureaus. How much there is of it, how much rain falls, depends on the amount of water in the rising air, on the height of the rise, on how long new air keeps on rising to feed the cloud-making and rain-making machine, and so on.

Precipitation is measured in inches. An inch of rainfall means that enough water has fallen to cover the surface of the earth beneath the shower one

inch deep in liquid water. That means over one hundred tons of water per acre or, nearly 25,000 gallons. On a square mile an inch of rain amounts to about 65,000 tons or over fifteen million gallons. Two or three billion tons of water may fall during a heavy, wide-spread rain.

The rainy places of the earth must have these four essentials of rain: Moist air, something to cool it, dust to condense the cloud droplets, vertical circulation to make these into rain. Deserts, and other dry places of the earth lack at least one of the four essentials. Most of the deserts are dry because the air over them has already lost too much water by rain, usually caused by mountain barriers. To lose water by rain decreases the humidity of the air, as has been said. The essential most commonly lacking in desert areas is moist air. Too much vertical circulation is also characteristic of deserts. The overactive vertical circulation milks the moisture out of the air on the rim of the desert. But when rain does fall on the desert, it is almost always of the violent type called a cloudburst. The intense vertical circulation of desert air literally knocks all the water out of the air at one time.

Every one has noticed that the first swift raindrops of a sudden summer shower are larger than those which follow. These first drops have swept through a larger mass of rising cloud and have had more opportunity to pick up small companions on the way. These larger drops then fall faster and reach the earth first.

They hurtle through the air. They spatter on the roofs, the trees, the ground. The procession has disbanded. It is raining!

Chapter 3

HEAT WAVES AND COLD

MAN can get used to any kind of temperature that this earth has so far been able to cook up. It may take a million years of evolutionary adaptation, but eventually he can live near the poles at 70 or 80 degrees below zero, or on equatorial deserts at 120 above. Man can live, and does live, on either end of a 200 degree gamut of temperature—just about twice the range to which the dweller in milder climes is subjected.

Nor do these extremes mean to their respective endurers the torture which they would inflict on dwellers in temperate zones. Extremes of heat and cold are normal in the Tuareg and Eskimo scheme of things; they do not mind them because they know no other condition.

An extreme temperature, then, if the extremity be a normal condition, is not the species of weather which is so obnoxious to man. It is the abnormal weather, the sharp, unexpected movement of temperature, that irritates and discommodes and oppresses him.

Yet it is not so much abnormal, unseasonable weather as weather that is super-seasonable. Not a cold spell in summer is objectionable so much as a very hot spell. Not a winter thaw so much as a winter week ten or twenty degrees below zero.

Waves, in other words; heat waves, cold waves.

Those are the sections of weather that man so bitterly complains of. One hundred degrees of heat brings worse suffering to Chicago than 130 does to the Sahara. Ten below in New York is crueler than eighty below at Point Barrow. Not the heat nor the cold but the change brings the grief. Mysterious —partly because they are so dreaded—are these waves to their victims. Yet their nature and origins are simple.

Weather is being spread over the map. Athabascans are sharing their cold with Pittsburghers. Senegambians are politely passing the heat. Samples of living conditions are being distributed as hints of what extremes of temperature are really like. But the recipients are not even thankful that the samples are only samples. They like their weather mild, do temperate zoners, and their sales-resistance to extreme styles is impregnable.

Seasonable weather—what there is of it—is so commonly understood that it is referred to here only for the sake of the record. The axis of the earth is tilted with reference to the plane of its orbit around the sun so that each hemisphere is tilted, now toward the sun for half a year, then away from it for the other half. When our hemisphere is tilted away from the sun, in winter, less light and heat reach it and it is cold. In summer, when we are tilted toward the sun, our weather is warm. The poles, tilted farther away for almost half a year at a time, are cold. The tropics, never tilted very much, are warmer. The equator, spinning around all year almost directly under the noonday sun, is warmest of all.

This being generally true, why are there spells of warm weather in winter? Why are there spells of

cold weather in summer? Why are there stretches of winter weather that seem colder than they ought to be? Why are there whole weeks of merciless hotness in summers when heat, but less of it, is a matter of course? Why is a heat wave, a cold wave?

All because of the circulation of air. All because chunks of air, streaks of air, whirls of air move up and down, across and about, always going somewhere, always shuffling in and out, over and under other patches of air—weaving a blanket around the earth that ravels before it is knotted. If the air did not move there would be no heat waves, no cold waves.

If the atmosphere stuck to the earth like a layer of gelatin all weather would be seasonable. Spring would drift gently into summer; summer temperatures would glide smoothly up and up until they began to slide down again; autumn would slip easily into winter. On any given day this year the temperature of any place would be just about the same as it had been the year before. The temperature of any given spot on the globe would be determined by the amount of sunlight and sun heat it received, and only by that. In New York City, for example, the summer sun is above the horizon for fourteen or fifeeen hours a day, and high above the horizon. A certain amount of the sun's energy is received, and the amount is the same from year to year. Similarly, the low sun of winter shines on New York City for only nine or ten hours a day, neither more nor less in one winter than in another. If there were nothing to interfere, New York City on July 4th, 1929, would be just as hot as it was on July 4th, 1928, and December

25th, 1930, would be no colder than December 25th, 1929, 1928 or 1828.

But the air will not stay put, over New York City or any other place. So there are heat waves and cold waves and all manner of annoyances and discomforts. The air, then, because of its restlessness, would seem to be a positive nuisance so far as temperature is concerned, worth bothering about only because it is a useful thing to breathe.

In reality, however, the air is decidedly a comfortable thing to have about the earth. It moderates the sun's rays so that they do not burn up everything and, having tamed them into pleasant heat, it keeps that heat on the earth's surface so that the planet does not freeze when the sun goes down.

Tremendously important is this first duty of the air, so important that it must be understood before the nature of hot waves and cold waves can be clearly comprehended. The quantity of light and heat, scientifically termed "radiant energy," which the sun sends to the earth has already been mentioned as equivalent to the burning of about 100,000,000 tons of coal a minute; a fact as inconceivable as are most other facts about the heavenly bodies. If that unimaginable amount of heat poured down on the earth's surface unimpeded by the atmosphere, crops would dry up like cinders and burst into flames; the oceans would boil away as steam; every living thing would wither and die. The earth would be in the same sad fix as the moon.

Spots on the moon on which the sun is shining become very hot—probably hotter than boiling water. There is no air around the moon to act as an

insulating blanket against the devouring rays of the sun by absorbing them. But a few minutes after the sun sets, the spot on the moon has cooled until its temperature is a hundred degrees or more below zero. There is no blanket of air to hold in the heat which the sun has been providing during the lunar day. These day and night temperatures of the moon have been taken by scientists with instruments attached to the great telescopes of the Mount Wilson Observatory in California and the Lowell Observatory in Arizona. Heat rays given off by the moon's surface before and after sunset have been measured and the temperatures computed.

On the earth the nearest approach to the airless condition of the moon is the tops of high mountains. At even ten or fifteen thousand feet above sea level, it is always very warm in the sun and very cold at night. The thin air of the mountain tops interposes little resistance to the sun rays during the day. After sunset, although the rocks have absorbed a good deal of heat during the day, they cool off rapidly because, with only thin air to hold it back, the heat radiates unhindered into space.

Some heat, of course, is radiated in spite of the air. A million miles or so in space delicate instruments would catch a few feeble heat rays given off by the earth, and eventually these rays must equal in heat the amount of energy received from the sun; otherwise the earth would keep getting hotter and hotter.

Not the air itself, but the impurities in it are chiefly responsible for its protective efficiency as an insulating blanket around the earth. Really pure air would permit the earth to bake and freeze alter-

nately almost as violently as does the moon. In text books the constituent gases of the air are given as oxygen and nitrogen. Neither of these absorbs much sunlight, or does much to hinder the radiation of heat from the earth.

But together with the oxygen and the nitrogen there are present in air, as slight impurities, carbon dioxide, which is the gas of soda water; water vapor, and ozone. All three of these gases are efficient heat absorbers. There are such small quantities of these gases in even the densest air that the most exact chemistry is needed to find them, but the total amount of atmosphere is so great that even these small traces of the necessary impurities make it fulfill its blanketing function very ably.

Ozone especially, with a truly trapper-like cunning, is a great little trapper of heat.

The sun itself even creates the ozone which ensnares the sun's rays.

Sniffing a breeze off the sea, nine people out of ten murmur something about the delicious smell of the ozone and allege further that nature is grand, or words to that effect. Unfortunately for romance, it is not ozone that they smell. What the breeze brings them is delicate whiffs of seaweed, fish, clams, and other shore-dinner constituents in a definitely deceased condition. The smell of ozone is much more nearly like that of ammonia or of the gas from burning sulphur. Its peculiar acrid smell can be detected near the quartz lamps that produce ultraviolet rays or near places where sparks form around electric power plants, for both ultraviolet rays and electric sparks have power to create ozone in the air.

Nor is ozone a gas of the sea shore. Close to the

surface of the ground there is almost never enough of it to smell. High in the air, however, the spectroscope shows the ozone in considerable quantities; modifying the sun's rays—luring them into an unbroken layer of traps fifty to a hundred miles above the earth!

Ozone is really ordinary air oxygen in disguise—atoms of oxygen which have been combined with each other in an un-oxygen-like way; as different from oxygen as fine smoking tobacco is from old-fashioned plug. Ordinary breathing oxygen is composed of atoms fastened together two by two—O_2, as the chemist writes it in his shorthand. Ozone is these same atoms clinging to each other in threes—O_3, a chemical triangle that is as easily broken as a human triangle, for ozone decomposes into two-atom oxygen even more readily than oxygen becomes ozone.

Sunlight traps itself in the upper levels of the air by home-wrecking the union of two oxygen atoms so that a third atom joins them. It is the ultraviolet rays that do the trick.

Sunlight is a combination of many kinds of rays; some corresponding to the colors of the spectrum, others that are invisible. The ultraviolet rays are those which cause sunburn. Air filters out and absorbs most of these rays, which is a wise provision of nature, for the worst sunburn in recorded history would look like underdone pie crust in comparison with what unhindered ultraviolet rays would do to the faces of mankind.

In the upper reaches of the air the ultraviolet rays are more intense because they have been only partially filtered, which is why mountaineers and aviators get so badly sunburnt. Near the earth the ultra-

violet rays are weaker, largely exhausted by making ozone in the air.

Most of the ozone is formed high in the air, where the ultraviolet rays are still strong. Gradually this ozone changes back into ordinary oxygen as the triangle ceases to be eternal, but meanwhile more ozone has been formed. The cycle is continuous; ozone is created out of oxygen and changed back into oxygen to make more ozone. The ozone is woven into the blanket of air by the ultraviolet rays; which although they themselves have little heat, are probably the main agent in the heating of the earth.

Thus the drama plays its theme of poetic justice high in the air: The sun, seeking to conquer the earth, sends down ultraviolet rays. These, in destroying the union of oxygen atoms, create an enemy, ozone, that turns against the rays and stifles them.

This explains why the earth is warmed enough but not too much, and why it retains much of the sun's heat so comfortably throughout the night. Beautiful is the picture; the whole earth gently warmed by the self-sacrifice of the air except in those spots where the natives revel in extremes of temperatures. Satisfactory, indeed, is the conduct of the atmosphere so far.

But into the placid scene steps air gone wrong, restless air whose eccentric and ill-considered wanderings mess up the tastefully arranged gradations of heat and cold. Innumerable are the complications wrought by the movement of the atmosphere. Cool breezes on a summer's day, warm rains in winter; northern lands warmer than they ought to be, like Scotland; equatorial areas of relative cold, like parts of East Africa; long dry spells, forty-day

downpours; heat waves, cold waves—all because of the sad fact that air moves.

Air moves because it is a gas. As already explained, gases expand when heated and contract when cooled. Air expands or contracts; that creates its movements.

There are three ways to heat anything: by contact with something that is already hot; by radiant heat; by some internal change. Water can be heated by putting a pan of it on a hot stove, by setting it in the sun, or by adding to it a chemical, such as caustic potash, which produces heat by its chemical reaction in the water.

The air is heated in the same three ways: by contact with the earth or with things on it which have been heated by the sun; by absorbing the radiant heat direct from the sun; by an internal reaction in which increase of pressure takes the place of the chemical in water.

Reverse action on the part of these three things cools air. Warm air in contact with a glacier or cold sea water becomes cooler. Warm air allowed to remain still cools off by radiating its contained heat. And when the pressure of air is decreased, it cools. Other things have to do with the case—rain and snow, for example—but these are less important.

For practical purposes, the matter of pressure is the most important of the three agents which heat or cool air. Air close to the ground is seldom cooled by radiation or by contact with cold objects. A patch of air over a given portion of the earth is most apt to be cooled by a lessening of its pressure.

But it is still more likely not to cool off quietly over that given spot. It streaks off across country

in the guise of a cool breeze on a summer's day, or an icy blast that drags the winter temperature still lower. The spots on the earth that are chilled by this breeze may be miles and miles away from where the cooling happens. Over these spots batches of new air, already cooled, are taking the place of the warm air. The warm air that has been displaced rises higher and itself cools off—by meeting with decreased pressure and by radiating its heat in the upper strata where such loss of heat is more easily accomplished.

This is what happens to the air, and it happens incessantly. Not only is there the continuous vertical circulation described in the chapter on rain, but great air currents, Gulf Streams of the sky, flow horizontally over the earth, creating the winds that bring hot or cold air from one part of the world to another.

What starts this streaming of the air? A change in pressure, somewhere.

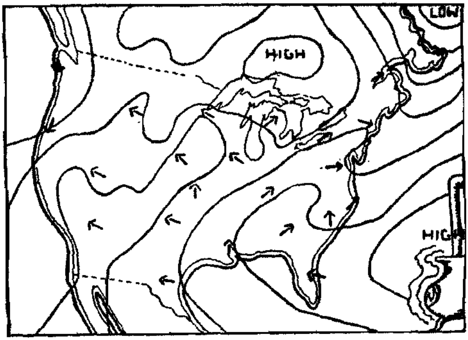
When one of the much detested heat waves of the eastern United States has lasted for more than a day or two, those morbid-minded victims who like to dwell on their misery read a good deal about the "Bermuda High." Onion-covered mountains the phrase suggests, but the real meaning of the words is the area of high air pressure near the Bermuda Islands. The notorious and plentifully cursed elevation is one of air pressure. This happens when winds or world temperatures or something else make the pressure of the atmosphere over a vast area of the Atlantic surrounding the Bermudas greater than normal. The air is heaped up in a dome, like a hill of loose sand. The pressure at the bottom is increased by the weight of the air dome over it. Currents of air, trying to bring the pressure down to

normal, flow outward from the dome toward its rim.

On one part of the margin of such a dome of warm, high pressure air over Bermuda lies the eastern part of the United States. From the dome, warm, moist air flows toward the shores of the United States and inland over the continent. This air, naturally warm from its contact with more tropical climate, has been further warmed by the increase of its pressure. It is moist because for days or even weeks it has been sliding along over the ocean, from which it has absorbed millions of tons of evaporated water. So long as the high pressure lasts around Bermuda, so long will the eastern United States suffer unusually warm weather.

And so long as the heat wave continues, perspiring citizens will inform each other that it isn't the heat; it's the humidity. For once, the citizenry is right. Dry air quickly evaporates perspiration from the skin and so helps cool the body. But the aerial curse from Bermuda is almost saturated with water; it will not absorb even a little sweat. Hence, collars and tempers wilt and the eastern United States staggers along under the most damnably uncomfortable weather it ever gets.

Desert heat is entirely different in its origin. Part of it is radiant heat from the sun trapped by the air itself, part of it picked up from the heated ground. And it is far more intense than anything that the Bermuda High sends out. The present world's record for high temperature was made at Azizia, an Italian weather station in the northern African desert. There, on September 13, 1922, the thermometer registered 136.4 degrees in the shade. The United



WHEN THE "BERMUDA HIGH" BRINGS A HEAT WAVE ABOUT.

A simplified weather map of July 20, 1928, the fifth day of a heat wave in the Eastern United States. The black lines indicate air pressure, decreasing outward from the "high." The arrows show the directions of winds. Warm air from the ocean and the Gulf of Mexico is being forced inward over the continent. If the air currents flowing from the "high" were not so moist from their travels over miles of ocean, this special variety of heat wave would not mean so much discomfort to the eastern part of the United States. Dry air evaporates the moisture from the body and so helps to cool it, but humid air is already so saturated that it can absorb little if any perspiration. Death Valley, California, is not so oppressive at 134 degrees of dry heat as is Boston at 100° of high humidity. Cold waves in the United States are most frequently caused by the cyclonic storms which whirl cold air down from Canada.

States record is nearly as high; 134 in the shade, on the edge of Death Valley, California. Hot as such temperatures are, they are dry heat, not really so oppressive as moister temperatures of 105 or 110 degrees along the Atlantic seaboard of the United States.

Equivalents of the Bermuda High are in operation here and there about the world, busily engaged in sending out waves of heat to oppress and discourage their victims. Elements of topography, sunshine received, and prevailing air movements dictate the location, nature and potency of these disturbers of atmospheric peace.

Heat waves, however, are but half the story. The eastern three quarters of the United States must submit not only to the hot breath of the Bermuda High but to the freezing blizzards which sweep across the country, playing hob with railway trains and ears and noses. These cold waves are air movements too.

Vast whirling storms called cyclones rush across the United States, especially during the winter. They resemble in many ways the hurricanes or tornadoes of the Caribbean. The motion of these whirls over the United States is such that their eastern edges move northward and their western edges southward. The northern edge, since the whirls are hundreds of miles across, reaches well up into Canada. When the cold air of that region has been spun around west of such a cyclone and has reached more southerly places, it has been gone only a few days from Canada. Naturally, it is still cold. It has been imported into the United States so quickly that it has had no time to warm up.

Excluding other and minor details, that is the why of many of the cold waves. A vast river of cold northern air has been drawn by the movement of the general atmosphere over the shivering country.

Cold waves are much the same in other parts of the world. Cyclonic storms of the same character sweep southeastward across Northern Europe from the Arctic. Behind them are currents of cold air. Thus England and the western portion of the continent get their cold waves.

Extreme winter cold of mountain tops is caused less by these movements of the air than by direct exchange of heat radiation. The winter sun brings little warmth. There is less air, or thinner air, to hold down the heat of the mountain top. Thus the high mountain plateaux, such as those of the Rocky Mountain region, have colder winters than mere air movement would bring them.

When both air movement and radiation combine to lower the temperature, there is apt to be extreme, terrific cold. The worst of such spots, so far as is known, is in northern Siberia—the "Pole of Cold," colder than the actual poles. At Verkhoyansk, in this unenviable part of Siberia, the coldest temperature ever recorded on a thermometer was reached, on January 15, 1885. It was 90.4 degrees below zero. There have been unofficial reports of temperatures below 100 below zero from the same unblessed neighborhood.

Far away, however, are Azizia and Verkhoyansk—far away from each other and far away, fortunately, from those to whom extremes of temperature are unbearable. Victims of hot and cold waves may blame the restless air, but they should not be too severe, for

if there were no air or no impurities in it, there would be, instead of occasional waves of heat or cold, a heat wave worse than Azizia's every day and a cold one worse than Verkhoyansk's every night.

Chapter 4

CHANGING SEASONS

EVERYBODY old enough for reminiscence agrees that weather isn't what it used to be. Winters are colder, summers are hotter, spring and fall come later. The present older generation, that is, thinks these things about the weather. What their predecessors thought doesn't matter.

The favorite weather of all true reminiscers is the old-fashioned winter, invariably termed good as well as ancient. Like most other things so called, it is difficult to see wherein its virtues lay or why its familiars speak so well of it. Evidently it was the style in its time, however, and since that time was indubitably superior in every respect to any other time, its modish winter must have excelled all others before and since.

It was, one gathers, a winter of special and meticulous severity, of a severity severe in every detail from length of skating season to depth of snow drift. No opportunity for record-breaking was allowed to escape, no potential severity was neglected. There were no soft spots. Every minute of it was severe. Through and through it was a good old-fashioned winter.

Convenient to Thanksgiving Day, it began with a tremendous snowfall which immediately piled up in drifts exactly six feet high. These drifts remained six feet high until they disappeared overnight in time for May Day. Since the good old days were not

cursed with plumbing, it was advisable to tunnel through these drifts, and thus many a jolly hour was whiled away.

Beginning with the snow, all lakes and rivers froze solidly into perfect skating rinks. It was characteristic of the old-fashioned winter that its snow never in the least marred the skating. Snow that otherwise would have piled up on the ice went to make the six foot drifts. Nature's rinks were open for exactly six months.

If there ever was a thaw it was the most severe thaw ever known, and it took place at such a time as would make it notable. Christmas Day was a good time for thaws, when there were any. In general, however, the thermometer stayed below zero from November to April 30th at midnight; during which time ears, apples, toes, noses and potatoes froze solid and remained that way, thus providing wholesome merriment for all. No wonder reminiscers take pride in good old-fashioned winters, and no wonder that they, whether bankers or cracker barrel scientists, agree that winters of to-day are shorter, warmer, and later. One hopes they are right.

Irreverent scientists who keep records of the weather do not agree with them. They go back as far as 1780 in order to disagree. In that year some old meany hung up a thermometer at New Haven, Connecticut and began to keep records that have been kept ever since. Almost a hundred years later General Greely came back from Greenland so full of anecdotes about the copious weather he found there that the country became one big family of weather fans and the Army put on a weather service which became the United States Weather Bureau. Thus the spoil

sports have a lot of data on which to base their contention that there has been no great change in winters—or summers either.

Right there in New Haven, for example, one of the very coldest winters since 1780 was that of 1917-18. And one of the warmest was that of 1876-77, precisely in the period when old-fashioned winters flourished. At New Haven the average yearly temperature has never been lower than 45.2 degrees nor higher than 52.7. Spreading this difference over a hundred and forty years makes it very thin proof of any change in New England climate. Nor do the Weather Bureau records show any general decrease in either cold or snowfall for the country as a whole.

With accurate records opposed to accurate memories, both must be right. Which is precisely the case. Weather isn't what it used to be, and it never was. There have been mild winters in the past as well as severe ones; cold summers as well as hot ones. There always have been such notable seasons and there always will be. It all depends on which seasons one remembers, and the seasons of one's youth are the most memorable. Many of the most abnormal seasons are remembered in formal history.

The summer of 1260 in England was a tough one, according to Matthew of Westminster, who observes that "great and enormous prodigies were seen in the air so that some said the last judgment was close at hand." The thunderstorms were so continuous that no one dared leave his house and the hailstones were as thick as three fingers and sometimes as thick as fifteen fingers. A famine was the result of this old-fashioned summer.

During most of the Fourteenth Century Europe suffered from extremes of climate. There were winters when the great rivers were frozen for months at a time. For fifty-five summers thereafter tremendous floods occurred. Other summers, notably the "hot summer of 1357," were marked by long droughts. The whole year 1594 was unusually wet, even for England, and among the curious weathers of 1783 was the so-called dry fog, a smoky haze that hung over Europe and America for weeks at a time during that summer. Benjamin Franklin traced a connection between the diminished heat of this summer and the excessive cold of the winter that followed.

The "year without a summer" was 1816. There was ice and snow in every month, according to contemporary writers. People wore overcoats in July.

There was a group of warm summers in the middle seventies, and another between 1889 and 1901—the latter group bringing warm winters with them. As everybody remembers, the early summers of 1926, 1927 and 1928 were unusually cool and rainy. The late summers of the first two of these years were warm and dry. To people of a following generation they will have been old-fashioned summers. But cool as was the summer of 1927, those of 1903 and 1905 were cooler. And there will be colder winters than that of 1917-18, the "war winter" that was so cold and snowy that even the railroads were interfered with. Eventually this will be remembered as one of the old-fashioned ones.

Reminiscers also assert that spring doesn't come so early as it used to, or that there isn't any spring any more. So far as several recent springs are con-

cerned, they are almost right. The springs of 1927 and 1928 not only came late but amounted to very little when they did arrive, being succeeded almost immediately by summer.

But there is no reason to believe that theirs is a permanent condition. Spring will come early again, and will last long enough to satisfy all but the most determinedly reminiscent.

The reasons for such earliness or lateness of the seasons have not been established to the satisfaction of meteorologists. In the opinion of the authors of this book, seasons arrive early or late according to variations in the intensity of sunlight. In 1927 and 1928 the amount of heat emitted by the sun was slightly above normal. In addition, there was a larger discharge of ultraviolet rays. The increase in ultraviolet rays produced more ozone in the upper air and thus made the earth warmer. This evaporated more than the average moisture from the sea, altered the movements of the air and otherwise disturbed the operations of the great weather engine. One of the results was the relative lateness of the springs.

All this implies a variation in the intensity of sunlight. It is enough to say here that such variations exist and that they occur in cycles. For a time solar radiation will be intense; then it will diminish, only to increase again. The eventual result is waves of weather like waves of the sea: Cold winters, cold summers, hot winters, hot summers.

If the variation in the sun's intensity were the only factor that produced variations in weather, it would be possible to predict future climates with considerable accuracy. But, as usual, there are other things

that complicate the question. There are several layers, so to speak, of complications.

On top is the sun, with its varying intensity. Below comes the atmosphere, with its varying circulation. Underneath is the ocean, with all manner of varying currents hot and cold. No wonder weather is so mixed up. No wonder there is no weather in temperate zones but only samples, to quote Dr. Andrew D. White of Cornell. No wonder seasons are changing.

In all this confusion, it would seem really curious that there is enough regularity of weather to make a season. A season, after all, is a long and expected period of cold, warm, hot or cool weather, depending on the place of the earth in its path around the sun. The wonder is that this chaotic mass of weather can ever divide itself into four kinds.

There are such things as seasons because the axis of the earth is tilted; for which reason, at any given point in the earth's path around the sun one half of the earth is receiving more sunlight than the other half. Thus, while the north pole is tilted away from the sun and it is winter in the northern hemisphere, the southern pole is nearer the sun and the antarctic summer has set in. If the axis were not tilted, northern and southern weather would coincide.

As it concerned temperature, this variation in the amount of sunlight received was discussed in the third chapter. But the variation also affects the motions of the atmosphere around the earth, and since these motions in turn affect the seasons, it is necessary to explain how the sunlight moves the atmosphere.

The best way to learn how sunlight stirs up the atmosphere is to fill a bathtub with water and sit in it.

It will be seen that by stirring the water up one side of the tub and down the other a sort of whirlpool is created. Stirring the water repeatedly up and down the center of the tub creates two whirlpools, one on each side of the tub, joining together at the stirring line in the center of the tub. And so on. The possibilities are infinite. A good earnest bather with science in his heart could work out hundreds of different patterns of bathtub circulation. Each pattern would be determined by the way he stirred.

Heat will do the same things as the bather's hand. A really serious pattern-maker ought to acquire one of the old iron bathtubs still used in France. To accomplish the simple expedient of heating the tub instead of the water, gas burners are arranged in rows under these man-sized open teakettles. One fills the tub, lights the burners, and then, if prudent, turns them out some time before sitting in the tub. The heat from the burners produces patterns of circulation in the water similar to those in a heated teakettle. All sorts of patterns can be made by lighting burners variously.

If there were hundreds of burners under such a tub and if they were turned on and off singly and in groups, the inquisitive bather would get an idea, of a sort, of the earth's atmosphere, with the unceasing currents, swirls and whirlpools of its circulation. But he would not have an accurate picture unless he arranged to light rows of burners rapidly, at the same time turning off one row as soon as another was lit, like the bulbs of an electric sign. That would represent, partially, the distribution of sunlight over the earth.

If the world could be viewed from space it would

be seen that the sun shines on it in belts of light and heat parallel to the equator. Whichever belt is directly under the sun receives more energy than the others. When the axis of the earth is so placed that the sun is directly overhead at the equator, the belt which is receiving the most sunlight includes the equator itself. When the northern hemisphere is having its winter this sunniest belt moves south across the equator into the southern hemisphere, giving that half of the world its summer. During the other half of the year the situation is reversed; the belt moves north and the northern summer comes with it.

That belt of maximum sunlight is the atmospheric equivalent to the bather's hand or the alternately lit rows of burners under the tub. There are pools and currents and eddies in the air wherever the radiant energy of this belt is focussed.

If the bather could move his hand the same distance and depth and with the same force each time he stirred the water in the bathtub, the resultant patterns of circulation would be identical. And by the same token, if the same amount of sunlight reached the earth's climatic belts with no qualifying interference, the seasons would be almost identical year after year. No summer would be much hotter than another at a given point on the globe, nor would any winter be greatly colder than its predecessors. What differences there were would come at regular intervals.

Interference with the circulation of the atmosphere, however, comes from many sources. The sun itself sheds light of varied intensity; the amount of the ultraviolet rays varies. Also, there are what

the meteorologist calls "accidental variations," so named because their causes are not yet thoroughly understood.

If the bather in the tub changes the angle of his hand as he stirs the water; if he closes and opens his fingers; if a cake of soap floats in the tub—there will be differences in the system of currents and eddies and whirlpools aroused by successive stirrings. It would be difficult for the champion bathtub stirrer of the world to avoid making these differences. It is impossible, practically, to stir the water twice in exactly the same pattern.

So is it impossible for the earth's atmosphere to be stirred twice in the same pattern. The distribution of ocean currents is one of the disturbing factors—perhaps the most powerful single one. The varying amounts of dust in the air, by affecting the air's retention of heat, make another vast difference in the circulation. Belts of cloud affect the distribution of heat. The heating or cooling of the continents is another important factor. The list of causes of accidental variations could run into the hundreds, and the weather man must take all of them into account.

Most of these variations go back, of course, to sunlight; the fundamental cause of all weather. Ocean currents and air currents are controlled by solar energy, even though they may be modified by the rotation of the earth. It is only because science has not yet arrived at complete knowledge of the effect of sunlight on the earth that there is talk of "accidental" weather variations; as knowledge increases accidental variations will be displaced by specific causes. They will have been traced back to

variations in sunlight. The long-range weather forecasting of the future undoubtedly will use this complete knowledge of the variations in sunlight to predict with something like assurance the changes of atmospheric circulation which bring about the vagaries of weather.

Meantime, the giant hand of the sun stirs the atmosphere into eddies and pools, mixes season with season, and shoves weather about in all directions. Seasons are changing, indeed: Summers and winters are hotter or colder, earlier or later than they used to be. And they always will be hotter, colder, earlier, later than they used to be. They change, and then change back. It all depends on the sun.

But whether "old-fashioned" means hotter or colder, earlier or later depends on when you were born!

Chapter 5

THE WORLD'S CLIMATES

ONE thinks of foreign lands rather definitely in terms of climate. No matter what else enters the mental picture, the climate is inevitably the background against which sheiks, Eskimos, Hottentots, toreadors and the Prince of Wales are posed. The Congo means heat, Siberia means cold, England means rain, Spain is a blaze of sunlight, Greenland a sheet of snow. And a just connotation it is, for climate, as has been remarked by a thousand discoverers of the truth, indubitably makes the man.

Climates vary, fortunately for the spice of life, and it is unthinkable that they should not vary. Yet they would not vary beyond the extremes of polar cold and tropic heat, if it were not for a great diversifier of weather, the ocean. The ocean it is that deals out climate to different parts of the earth.

The word climate has been subjected to loose usage. Quite often only one of its components is meant when the word is used. When it is said that the climate of Florida is a hot one, only the temperature factor is recognized. Accurately, climate, which is a general term for the character of the weather month by month or year by year, includes three fundamentals: Temperature; rain or snow (precipitation is the technical term including both); and storms. Proper description of any climate takes cognizance of all three fundamentals.

Different portions of the earth have been classi-

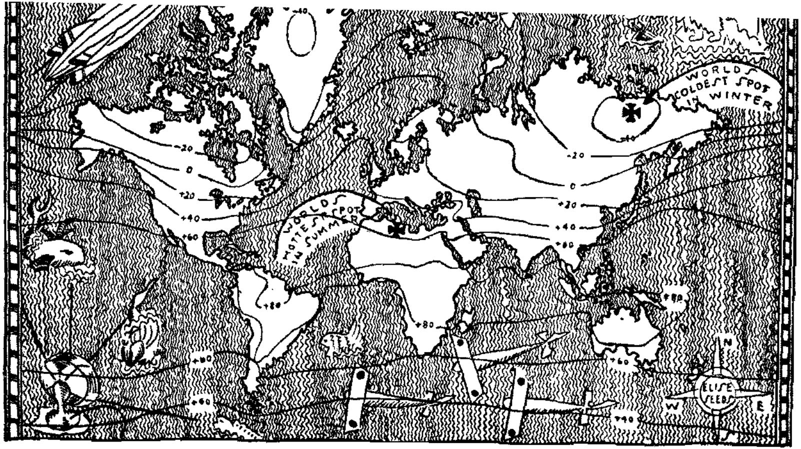
fied, of course, according to the three climatic elements. Like all classifications, the division of the earth by climates may be either very general, or elaborated to the point of minute differences.

According to temperatures, the earth is divided into the familiar torrid, temperate and frigid zones of the school geographies, and no doubt most pupils assume that straight lines like the equator and the tropics mark the divisions accurately enough. But many places equidistant from the poles or the equator, places in the same zone, differ radically in temperature. Scotland, for example, is about as close to the north pole as Manchuria, yet it is warmer. It is warmer than the part of Sweden which lies on the same parallels of latitude, separated from it only by the North Sea. It is even warmer than New York, which is hundreds of miles farther south. The latitudes of California are those of Japan and China, yet California is a great deal warmer the year round.

Neatly ruled "zones" will not do, obviously. A more precise mapping of temperatures is called for.

Lines drawn across the map to connect places of about the same average temperature are called "isotherms." They are equivalent to the lines of elevation which mark heights on a topographical map, only they mark the elevation of the temperature. And they are not straight lines parallel to the equator.

Very generally, of course, isotherms have a parallelism to the equator, because there are such things as torrid, temperate and frigid zones, after all. But seldom does a given isotherm parallel the crosswise divisions of the earth for more than a few miles. There are certain great bends and twists in the isotherms, as well as smaller curls and jogs.



CHILLS AND FEVERS THAT SPOT AND CHANGE THE WORLD'S FACE IN AVERAGE WINTERS.

The lines across the map are isotherms, marking the average temperatures in January. The North Atlantic is warmer than it ought to be; Central Asia is colder. In summer the isotherms move poleward.

Along the west coast of North America, for example, the isotherms head decidedly northward. Isotherms connect Southern Alaska with a point on the Asiatic Coast, which is as far south as southern California. Eastward across the Atlantic Ocean there is the same northly bend of the isotherms. Northern Scotland and Chesapeake Bay have approximately equal average temperatures. England is in the latitude of Labrador but has the temperature of New Jersey.

Over the continents, on the other hand, the isotherms head south. Central Hudson Bay is in about the same latitude as Scotland, but, as the isotherms show, its temperature is as cold as that of northern Greenland. Northern Siberia is in about the latitude of Finland but its isotherm is colder than that of the North Pole.

Isothermic maps, then, show the arrangement over the earth of one factor of climate: temperature. Precipitation, the second factor, has also been mapped out.

But there is no such regularity in the distribution of rainfall as there is of temperature. Rainfall is a much more complicated matter, since it involves not only heat but winds and the vertical circulation of the air. The reasons why any given area of earth receives its average amount of rainfall can be stated after studying solar radiation, air currents, ocean currents, topography, and so on, but the reasons apply only to that area and may not be duplicated in any other part of the earth.

Temperature and rainfall are the factors commonly used in mapping out climates. The third factor, that of storms, has not been well mapped for the

world as a whole. Yet a map of storminess would probably have greater value in indicating what climate means to humanity than any other of the standard maps. Storms make the history of a race.

Professor Ellsworth Huntington of Yale, unquestionably the foremost student of these matters in the world, believes that the relative storminess of Western Europe, Eastern United States, and Japan is responsible for the stimulating climate of these areas, which in turn is responsible for their relatively high civilization. The great and frequent changes in temperature which characterize storms spur on human beings to endeavor and achievement, Professor Huntington thinks.

"Storm" is one of those indefinite words like nation or party; everybody knows what they mean, but try to define them! A storm does not necessarily include high winds or rain but frequently it does include them. A rapid change of weather is probably the essential ingredient of a storm. The cyclonic whirls which move across the United States so frequently in winter are storms. So too are the summer thunderstorms. Each is accompanied by sudden changes in temperature, air pressure, rainfall, and so on, but the changes are different. Both are storms because they bring about these changes.

While few world maps of storminess have been made, individual storms and their paths across the earth are mapped out every day by the weather bureaus. The United States Weather Bureau, for example, publishes a map tracing the tracks of storms across the United States during each month. These cyclonic storms of the United States start south of Alaska, swoop down across the Pacific Northwest,

southeast through the Mississippi Valley, then east across the country and out over the Atlantic. Their track, in general, is in the shape of a bow.

From storm to storm these tracks vary considerably as plotted on the weather map but the maps for a month or a year show that they keep pretty well to the same general route, like ocean liners on the steamer lanes. And like the traffic lanes of the Atlantic, where liners head farther south in summer to avoid icebergs, so in winter the storms that cross the United States head farther south than they do in summer, presumably because of variations in solar radiation.

When the storms depart very much from their usual tracks the weather is exceptional. The summer storm tracks of 1927 and 1928, for example, were farther south than usual and there were more storms. Therefore, those summers, at least in their early months, were unusually cold and rainy.

The relations of storm tracks in other temperate-zone continents are not unlike those of North America. The storms of Europe start near the Arctic Ocean and head down toward Ireland. There they swing over to the continent in a northward-bowed curve like that of the North American storms. But they do not sweep across Asia to the Pacific. The Alps stop them and break them up. Storm tracks in Australia and South Africa course along in somewhat similar arcs but with motions directed generally toward the north and east instead of toward the south and east.

The world climates created by these three factors of temperature, precipitation and storminess would be extremely difficult to visualize on one map. It

would be so complicated as to be confusing, for after all, the three climate essentials are widely different things. One agency, however, controls and distributes climate in all its unlike essentials. That agency is the ocean.

The sun is the basic producer of climate. The atmosphere is the manufacturer. The ocean is the retailer. In another analogy, the sun is the mine from which the gold of climate comes. The atmosphere is the mint where it is turned into currency. The ocean is the banker, and distributes the currency.

Each year the earth receives a certain income in heat-money. Some of it is expended immediately in warming the atmosphere. Some goes to warm the continents. A vast amount, however, goes direct to the vaults of the ocean banking system. Here it is stored until needed, when it is sent out in the form of warm air currents, to be spent where it will do the most good.

The ocean currents that do the distributing are greatly similar to the other heat circulations—those of the atmosphere. The differences, however, are important. The air is a compressible gas. The ocean is an incompressible fluid. The ocean is heated at the top. The atmosphere, while it receives sunlight from above, is heated mostly from below by the sun-warmed surface of the earth.

This last difference is extremely important, because it means that most of the circulation of ocean currents takes place near the surface. If the teakettle used so frequently for illustration were heated from above instead of below, the water on top would move about as it heated up while that on the bottom

remained still and cold. Even when the top is almost boiling the bottom may still be cold.

That is why the depths of ocean are icy cold, and why there is little or no circulation of currents there. If these currents circulated at the bottom of the ocean, or even a few hundred fathoms below the surface, their effect on the circulation of the air and consequently on the climate would be practically nil.

If the oceans had happened to be made of any other liquid than water there probably would have been no such thing as climate. Water is the only common liquid that expands when it freezes, which means that ice is lighter than water. Thus the ocean freezes on its surface and the floating ice protects the depths from growing so cold as to freeze. Little heat is conducted upward through the blanket of ice and the water underneath remains water.

The ocean might just as well have been made of alcohol or petroleum or any other liquid, inconceivable as such a state of affairs would seem. Were this true, oceanic ice would sink. The ocean would freeze solid from the bottom up, all over the world. The warmest surface weather would melt only a few feet of ice on the surface. Thus there would be no ocean currents, no circulation of heat and no climate. It is difficult to imagine any other liquid taking the place of water on earth but it is almost certain that on other planets of the solar system, especially the outer ones, liquids other than water do prevail and that these planets have no such thing as climate.

Of the scores of ocean currents which have been charted the Gulf Stream is the best known and one of the most important. It is really one side of a great whirlpool in the Atlantic Ocean, whirling

northward on the North American side and southward on the European side. In tremendous volume this whirlpool carries warm water from the South Atlantic and the Caribbean Sea northward across the Atlantic to bathe the coasts of Europe. It comes closer to England and the western part of the European continent than it does to any part of the North American coast north of Florida.

Because of the Gulf Stream's warm bath the British Isles, Norway, Sweden and other countries of North Europe have mild, temperate climates instead of the Greenland climate to which their latitudes would entitle them.

A current of cold water, called the Labrador Current, flows down from Baffin Bay against the North American continent and cools off Labrador, Newfoundland and the northeastern United States. A similar routeing of currents exists in the Pacific Ocean: A warm stream moves northeastward from China toward Alaska, and a colder current flows westward, near the Equator, toward the Philippines.

All these currents are set going, of course, by the fundamental motive power of solar heat. Their pattern of whirlpools and eddies is regulated by the shape of the continents, by the rotation of the earth and by other factors. All move heat from one place *to another. Thus they distribute weather and climate* in its three phases: temperature, precipitation, and storms.

A favorite scheme of the Sunday supplements for many years has been that of damming the water gap between Cuba and Florida in order to stop the Gulf Stream and improve the North American climate. In discussions about this modest project speculation

has centered chiefly on the disastrous effects which the loss of the Gulf Stream would visit upon England. While such a dam might be built the truth is that it would probably have no effect of importance on the climate of the British Isles. The Gulf Stream is only one part of the vast Atlantic whirlpool. If this course were interfered with it would merely set itself a new route, probably dodging Cuba and Florida altogether, and go about its business of transferring tropical heat to Northern Europe just the same.

Climates on or near large bodies of water, as is well known, are more even and less subject to extremes than are those far inland. This is because of the equalizing effect of water. Large bodies of water tend to exchange heat with the air. A cold lake will lessen the severity of a hot wave along its shores; a warm lake will warm up cold winds blowing over it. Thus there are "oceanic climates" and "continental climates." The first are relatively stable and equable, the latter are characterized by sudden and severe extremes.

The ocean, in dealing out climate to different parts of the earth, seems to exercise sound and benevolent judgment. Where there is no ocean to attend to the job, the weather, left to itself, is all too apt to run amok.

Chapter 6

WEATHER RHYTHMS

IN all the welter of sun rays and scurrying winds and ocean currents that make weather it would seem strange if there were nowhere a regularity, a pattern, a rhythm. So many other things are tuned to rhythms. Light, heat, sound, all exist in waves. Even leaves and flakes of snow and feathers of birds and crystals of salt have their patterns. All move or grow to beats of time or space.

And so moves the weather. There are cycles of climate, periods of time in which weather swings back and forth as though it clung to the butt of a giant pendulum or throbbed in a cosmic pulse. There are such cycles and they beat time for the history of mankind.

So obvious is it that climate changes in cycles, and so important is climate to man, that scientists are devoting extraordinary efforts to the problem of identifying the rhythms of weather. Professor Ellsworth Huntington of Yale, who was one of the first to sense the mystery of climatic cycles, published a most remarkable book, "The Pulse of Asia," in which he shows that Asian climate has swung, at intervals of several centuries, between dryness and wetness; that these changes have been ultimately responsible for the history of that continent and have influenced profoundly the history of the world.

The problem is really like that of a detective story.

There is a mystery to be solved; the clues are scattered and obscure; some of them are in cypher. The mystery has lasted a long time. It will remain a mystery until all the clues are run down, checked and compared.

The idea that the climate swings back and forth has occurred to scientific men from Plato onward, but the real discovery of climatic cycles, which means the computation and verification of their length, is a modern achievement. Some of the longer cycles, those of centuries in duration such as Dr. Huntington deals with in "The Pulse of Asia" are only partly discovered; their lengths have not yet been definitely established. Other and shorter cycles, however, have been fixed with considerable mathematical exactness.

One of the most positively established of all climatic cycles is that discovered by the famous Viennese climatologist, Eduard Brückner, who died only recently.

For a number of years Brückner collected every weather record that he could find in Europe. He found temperature records going back to 1730, rainfall records to 1815, and a great mass of other and scattering data. By 1887 he had collated all his data and from his comparisons he deduced a cycle averaging *between 35 and 36 years in length.*

According to this cycle, 17 or 18 years of relatively warm weather in Europe will be followed by 17 or 18 years of relatively cold weather. Similar periods of dry and wet weather correspond with the changes in temperature.

Following Brückner's publication of his discovery this cycle of about 35.5 years has been discerned in weather records for most parts of the world. It has

been further verified in the growth of trees, in the movements of glaciers and in other conditions of nature on which climate has effects. Why there is such a swing of the pendulum and why it is 35.5 years long has not yet been discovered, but there is little doubt that warm, dry weather for 17 or 18 years is apt to be succeeded by a like period of cold, wet weather.

Brückner's discovery is not yet fifty years old, but some three centuries before that time Francis Bacon, one of the wisest men who ever lived, had evidently gained an inkling of the same idea. In his essay "Of Vicissitudes of Things," according to Professor G. C. Simpson's quotation, Bacon wrote:

"They say it is observed in the Low Countries (I know not in what part), that every five and thirty years the same kind and suit of years and weather comes about again; as great frosts, great wet, great droughts, warm winters, summers with little heat, and the like, what they call it the prime; and is a thing I do the rather mention; because computing backwards, I have found some concurrence."

Still another weather cycle of about eleven years has been established and almost certainly corresponds to the cycle of variation of sunspots. Even before the discovery of telescopes sunspots were observed by viewing the sun through a bit of dark glass. Actual records of sunspottedness kept for over two centuries show that these solar blemishes reach a maximum of number and extent about every eleven and a half years, on the average, the interval varying between seven and fifteen years. These sunspots are signs of exceptional solar activity and since the sun is the fundamental manufacturer of all weather, it is plausi-

ble enough that cycles of weather should correspond with cycles of the sun's condition.

The idea is, however, more than a theory. Plenty of corroboration is to be had by observation, especially in tropical regions. Because of varying rainfall or increases and decreases in evaporation, the levels of tropical lakes not too greatly affected by other conditions rise or fall in agreement with the weather. Some such lakes in Africa and Australia, it has been found, rise and fall in close correspondence with the cycles of sunspot activity. Times of high and low level of these lakes are about five and one half years apart. Every eleven years the lakes reach high water mark. Low water is reached at alternate periods of eleven years.

Other phenomena observed in Central Africa support the view that the eleven-year sunspot cycle is one of the cycles of climate. In 1911-1912 there was a great drought in Central Africa. Those were years of low sunspot activity, also of low level of the lakes. Eleven years later occurred another great drought, also at a time of minimum sunspots and when the levels of the Great Lakes, Lake Albert and Lake Victoria, were falling rapidly. To complete the human linkage, old inhabitants of Nyasaland have noticed that famines in that country occur at this same average interval of ten or eleven years.

This more or less regular occurrence of the droughts that bring famine was first noticed, so far as history tells, by the hero of one Bible story which even the most skeptical believe—the story of Joseph.

While Joseph was in jail because of a little scandal over Potiphar's wife, the Pharaoh then ruling Egypt had a dream which puzzled him greatly. Joseph

was pretty well known as the Freud of his time; he could wangle out of a nightmare far more sinister meanings than mere indiscretion with a welsh rarebit at midnight. So they let him out of jail long enough to talk over with Pharaoh the famous dream of seven fat kine and seven lean ones; of seven full ears of wheat and seven dry ones. What could it mean?

"Easy," *said Joseph, or words to that effect.* "The dream foretells infallibly, seven years of plenty and seven years of famine. Ask me another."

Now Joseph was one of the smartest men that ever lived, despite his misfortunes with the ladies, and it is quite possible that he seized the opportunity to promote his standing as a prophet by making from Pharaoh's dream a prediction that was almost certain to come true. Such a smart man must have been observant and it is more than likely that he noticed that the amount of water in the Nile waxed and waned in groups of years and thus brought alternate plenty and famine to the land of Egypt.

And it may be that in predicting a fourteen-year cycle half bad and half good, he was more accurate than modern records would indicate. The rise and fall of Central African lakes now show, it is true, the shorter, eleven or twelve-year cycle, but it may well be that in Joseph's day the half cycle of rainfall and drought in Africa really was seven years—for weather cycles seem to change a bit from century to century.

Indeed, he may never have said seven. A lot of things have happened to the transcripts of his words in four thousand years. Seven was—and is—a sort of sacred, mystic number, and the recorders of Biblical history would be desirous of getting that

number into the archives somehow in order to tie up Joseph's practical intelligence with their version of the supernatural. Anyhow, there is not too much difference between six and seven, and Joseph seems to have been the first man to identify a climatic cycle and put his knowledge to use—a better use, in fact than any to which modern knowledge of such things has been put.

That the weather cycle had anything to do with sunspots is something Joseph may not have known. He may not even have known that there were such things as sunspots. Yet it is not impossible that he did. Chinese astronomers knew of them and counted them, and the priests of Joseph's time in Egypt were every bit as good at astronomy as the Chinese brethren. If he knew of sunspots and watched the rise and fall of water in the Nile he must have seen the connection, for the cycle of sunspots is not only related to the cycle of African rainfall but is identical. Both cycles are eleven years long and they begin and end in the same years.

African climate is not the only verification of this theory of sunspot-climate linkage. The records of humble thermometers and rain gauges, if kept long enough, support it. In parts of South America the weather has been shown to follow roughly the week by week variations in the intensity of sunlight. Australian rock deposits two hundred million years old show that the sun has been following its eleven-year cycle of varying intensity all that time. Marks left by Swiss and Canadian glaciers show that they have advanced or receded according to the same cycle. Layers of clay deposited each spring for thousands of years on the bottoms of Swedish lakes and estua-

ries, similar layers recently dredged up by Soviet Russian scientists from the bottom of the Black Sea, variations in the annual growth rings of trees in California and Arizona, all supply additional corroboration of the eleven-year sunspot cycle as affecting weather.

If only this eleven-year cycle or the slightly longer Brückner cycle affected the earth's weather, the weather forecaster would have an easy time. Every eleven years or every thirty-six years would be like every other eleven or thirty-six. There would be cold winters and summers for a while, then hot winters and summers for a like period. But any one who has lived more than thirty-six years knows that while traces of these cycles may show they are in operation, something else is also at work to nullify the regularity of climate which the cycles might bring.

That something else is a host of other cycles, some short, some long, which hopeful scientists have announced as discoveries from time to time. A cycle of fourteen months is discerned by one climatologist. Others are: 28 months, 30 months, 16 years, 44 years, 95 years, 372 years. Recently there has been great talk of the "Jupiter Cycle" of about 96 years—an astronomical cycle based on the length of time it takes the more important planets of the solar system to swing around the universe and get back into their former positions with regard to each other and the sun.

It is notable that none of these cycles is the same as the earth's own cycle, the year that it takes the earth to go around the sun. None of them consists of an even number of years, with no fractions left over. Evidently the earth does not amount to so much,

after all, if its cycle and those of the weather inflicted on it cannot synchronize.

Presumably there are a great many of these weather cycles. Unquestionably some of them are centuries long. They might be thought of as waves in the sea; some higher than others but with a rhythm, a scheme of repetition so that between every two high waves there are repeated series of smaller ones.

Or as of a great many clocks all ticking at once. Some tick every second, some every eleven seconds, some every thirty-six seconds and so on; while still others tick at odd intervals such as five-sevenths of a second. On first hearing, such tickings would seem to constitute an unsortable chaos. Sometimes the ticks would coincide, sometimes they would not. No rhythm or regularity would be apparent. But by careful listening it would be possible to figure out the periods at which various of the clocks were ticking. A graph showing by means of a line the periods when each clock ticked would be exceedingly and irregularly saw-toothed. It might not show the cycles of which it was composed until it had been studied for a long time.

So with a graph showing climatic cycles; for example, the matter of rainfall. It is probable that dozens of different cycles are affecting rainfall at the same time. At one time several of the cycles may be operating toward the same end, like clocks that happen at a given moment to tick simultaneously. If several cycles happen, in a given year or month, to be urging increased rainfall, that year or month, will be very wet. At another time several cycles may be swinging the other way and the weather will be

very dry. When the cycles are opposing each other, like clocks alternating their ticks, the weather will be moderately wet or dry.

At present only the two of the weather clocks represented by the sunspot cycle and the Brückner one have been identified by their ticking. When the rest have been listened to long enough they too will have been timed as accurately as these eleven and thirty-six year tickers. Fortunately, it will not take centuries to listen to all the tickings of even the clocks with the longest pendulums, for a great many of these tickings have already been recorded on the graph of history. They are the clues over which scientific detectives now pour.

In all ages a few sturdy persons have kept diaries; and the essential entry in all diaries except those which supply divorce evidence is the state of the weather. Archivists of more official flavor are also given to noting that it was fair and warmer after Hannibal crossed the Alps and that Gaul was divided into three parts the year of the big wind. Droughts, floods, great storms, old-fashioned winters—all sorts of weather has been made immortal by one kind of history or another.

Weather data pop up in the most unexpected places for the climatologist to leap on. Old English tax records, for example, gave scientists something to gloat over not long ago when it was discovered that the records revealed such clues as the yields of grain and the flow of water in mill streams year after year. Records of the stages of the Nile for centuries are perpetuated in the Egyptian hieroglyphics. When the clay-brick libraries of Babylon have been fully deciphered—and after other kinds of scientists

have had their fling at dynasties, wars and religious beliefs—the translation will probably be tossed to meteorologists and it will be seen that Babylonian weather records were kept and that they help establish the chronology of climatic cycles.

These are all human records; they go back no further than the time of literate men. Records of another sort can and do go back much further. Nearly three thousand years of weather records—cipher clues to the great mystery—have been obtained by Professor Ellsworth Huntington of Yale and Professor A. E. Douglass of the University of Arizona by studying the growth rings of trees, especially of the Big Trees of California. These trees are of astounding antiquity; the oldest one studied was 3,210 years old when it was felled.

Each normal year of their lives these trees add growth which shows in the cross section of sawed-off trunk as a ring. In years of tree-plenty the ring is stouter than in those of famine; too much rain or too little shows in the character of the ring. By measuring some of the later rings and comparing these measurements with existing weather records, Dr. Huntington and Dr. Douglass were able to make a sort of scale which, applied to rings for years before existing weather records, would show what the weather had been for those earlier years.

To prove how accurate this record might be, Dr. Douglass picked out an old pine stump, studied its rings until he identified a group of narrow ones which represented several years of drought which he knew had occurred. Then, by counting the rings outside of that narrow group, was able to state in what year the tree had been felled. The owner of the land

on which the stump stood verified the date. Thus the accuracy of the tree-ring method of reading weather history was supported.

Following this method Dr. Huntington studied the rings in the stumps of some 450 Big Trees in central California. Some of those trees were saplings in the days of the Trojan War and the exodus of the Hebrews from Egypt. On the basis of their rings Dr. Huntington prepared a curve of climatic changes in California.

The main fluctuations followed quite closely the curve of climatic changes which he had prepared for Western Asia on the evidence of ruins and lakes. He had uncovered a weather history of three thousand years! In his book, "The Human Habitat," he says of the Big Tree that proved to be three thousand, two hundred and ten years old:

"It is interesting to find that this tree appears to have been almost killed by prolonged drought at the very time when various lines of evidence indicate a dry period in lands around the Eastern Mediterranean. In the Bible this dry period seems to be recorded in the so-called plagues which Moses is reported to have brought upon Egypt. If the miraculous element is eliminated, the rest of the Biblical record appears to be a straightforward and convincing narrative of exactly what would happen if the Nile fell to an extraordinarily low stage."

The next step in charting the weather history of the world is to study evidence older than that of the Big Trees. Trees offer convenient records, and already fossil trees many times older than the survivors of California are being measured for the story of their rings. But the growth of trees is subject

to so many complications that Professor Huntington's curve can be accurate in only a general way, not in detail.

The strand lines left in their basins by lakes which had no outlet also tell part of the story of past weather. Dr. Huntington studied several such in Asia; others exist in Africa, Australia and the desert region of the United States.

In a round pot-like hollow in the hills of Eastern California is a flat cake of salt and brine called Searles Lake, from which chemical corporations now extract potash and borax. Once Searles Lake was a real lake six hundred feet deep. When its level reached high enough it overflowed, filled another lake to the eastward and ran off finally into Death Valley. The highest water level the lake ever reached is plainly marked, to the eye of the geologist.

More than two hundred other levels of the lake, each a temporary shore line, have left their marks on the basin, forming a natural rain gauge. Since the water of the lake has dried up through evaporation, it is obvious from these strand lines that California weather was once wetter than it is now, and that it fluctuated as does weather to-day. The strand lines are not easy to date in years but their very existence and the scheme of their arrangement show, once more, that weather flows in cycles.

Glaciers supply still other evidences of climatic cycles. After long periods of cold, snowy weather, glaciers advance. After periods of warm weather they retreat. Sometimes one advance destroys the evidence of the preceding retreat but fortunately this is not always the case, and when glaciers have been more thoroughly studied—especially in the glaciated

region of the Central African mountains—the case for cycles of climate will probably be stronger still.

Layers of plant materials found in the peat bogs of northern Europe supply still more information. Some layers of such bogs are found to contain large quantities of pollen from pine trees. Layers formed in intermediate years contain less pollen. With the help of botanists it is possible to determine the character of the climate in the successive years.

Layers of clay deposited in lakes and estuaries, especially those into which glaciers discharge, are an even greater source of information about the past climates. Clay deposited in summer differs in color and character from that deposited in winter. In Norway and Sweden and in a few other parts of the world the lifting of the sea coast has exposed great beds of such clay in layers. Baron Gerard de Geer, a distinguished Swedish geologist, has studied these clay layers for many years. By interpreting the character and thickness of the clay layers the Baron traces with considerable exactness the climatic conditions of northern Europe for twelve thousand years, back to the time when the glaciers of the last great ice age were disappearing. This line of investigation promises to prove the most important of all. It has just begun, but already Dr. Chester Reeds of the American Museum of Natural History and Dr. Antevs of the Carnegie Institution have made studies of similar clay layers in America.

Precisely similar layers of clay and other material are found in rocks, some of them hundreds of millions of years old. The evidence of these rock layers proves that climatic variations have had the same character of moving in cycles for probably a thousand

million years of the earth's history. In Australia, according to Dr. C. E. P. Brooks, the sunspot cycle of eleven years has been identified in rock at least five hundred million years old.

Climatic changes in these great cycles cannot but affect human history, as Dr. Huntington has so ably insisted. The great changes in Asia, the drying up of Africa, its moister condition in Roman times, the changes of climate in Palestine recorded in the Bible—all these and more have affected human history radically and directly. While Dr. Huntington's view has been accepted by the vast body of scientific opinion, there are still scientists who maintain that such changes are not cyclic but "secular"; that is, that they progress in one direction instead of returning. This would mean that the earth is gradually drying up, instead of undergoing a period of dryness from which it will return to a wetter state, but fortunately the weight of evidence is against this idea.

One of the most important historical effects of climatic changes, as advanced by Dr. Huntington, has been that they caused the successive waves of migration out of Asia—the outpouring of the hordes of Vandals, Huns, Tartars, Mongols, and so on. These migrations have been going on for thousands of years. When there is a period of plentiful rainfall and food the Asian populations thrive and increase. When the cycle changes drought and famine sweep the hordes before them, flooding Europe and China.

Climatic cycles have made of Asia a pump, spurting jets of humanity every few score years.

Human migrations elsewhere in the world, even the migration from Europe to the Western world now current, may some day be shown to have climatic

elements behind them. So apparent are the evidences of cycles in history that Dr. Flinders Petrie, the distinguished British Egyptologist, has asserted that civilization itself rises and falls in long cycles. Some historians deny the existence of these historical cycles. Others explain them by reference to human psychology—ambitions, wars, inventions and discoveries—but cannot explain the recurrence of motives which lead to undertakings and achievements of historical weight. Still other experts believe that those cycles of civilization, rising to their peaks and tottering into their chasms, are based ultimately on vast cycles of climatic change.

The truth probably lies between the last two views. Undoubtedly there are such things as historical cycles but they are not so regular that they can be traced mathematically. Nor are they moved entirely by weather changes; psychology unquestionably plays its part. Yet weather cycles probably constitute the most important single pulse of history, for they make or break crops. Crops, in turn, are at the bottom of almost every change in the economic condition of the world or of any large part of it. And if there are racial ambitions, wars, or migrations which do not evolve from economic considerations, these have yet to be discovered by students of world psychology.

Of all the cycles of climate which have been suggested or discovered only one traces directly to a cause. That one, of course, is the eleven-year sunspot cycle. For this reason, perhaps, sunspots have been accused, recently, of more sins than charity can cover; and for the additional reason, probably, that the human mind has a tendency to grope for the

CLIMATE PULLED THE STRINGS OF ANCIENT HISTORY.

The wavy line at the bottom is Professor Huntington's curve of rising and falling rainfall, deduced from the growth rings of the California trees. The low rainfall in 1230 B.C. probably caused the Biblical plagues in Egypt. Greek philosophers thrived in happy times of much rain about 400. Low rainfall preceding 218 drove Hannibal across the Alps. Palestine in the time of Christ was more fertile and better watered than now. A gradual decline in rainfall coincided with the decline of the Roman Empire. Which is not to say that climatic changes are solely and directly the motivating factor in history. There are undoubtedly such things as historic cycles, and mass psychology plays a part. But what is at the bottom of historic cycles and mass psychology? Weather cycles, which probably constitute the most important pulse of history, for they make or break crops. Crops are the foundation of economic conditions, and from economic conditions spring wars, migrations and dynastic changes.

Since the time of Christ the curve of rainfall recorded by the trees and corrected by other data shows a general decline. The last two millennia have been drier than the preceding two. A considerable decline about 450 A.D. probably caused the invasions of the Huns. Mohammed's outburst coincided with another sudden decline just before 650. The Great Plague followed a sudden rise of rainfall after a low period. It happens, perhaps by mere coincidence, perhaps because of some mysterious natural law, that there had been a sharp decline of rainfall just before Columbus set out on his voyage of 1492, and that the discovery, exploration, and settlement of the new world was conducted during years of higher rainfall. The end of the line, the present era, is on a rising curve, but where the curve is headed for nobody knows, for the laws that determine weather cycles have yet to be formulated. When such laws are understood it may be possible to predict not only future weather but future history.

supernatural where plain nature suffices, theories of sunspot influence on human affairs have gained a credence undeserved until these effects are proved. Dr. A. Tchijovsky, of Moscow, for example, has offered discussions of the relations of the sunspot cycle to wars, riots, and other manifestations of human excitement. This writer cuts through or ignores subordinate causes of warfare such as famines, which might be brought about during maximum sunspot periods by disturbances of the weather, and assumes that some mysterious effluvium from the spotted sun irritates men and women or arouses them to excessive activity. It is conceivable, of course, that excess of ultraviolet rays would stimulate mankind during periods of sunspot activity and it would be foolish to assert that no such direct connection between sunspots and human activities will ever be discerned, but at present the verdict on the theory is the Scotch one of "Not Proven."

The effects of climatic cycles, whether through sunspots or not, may be seen in rather unsuspected places. Mythology, for example; for whole systems of mythology have been based on changes wrought by climatic shifts. Many of the myths and legends of northern Europe, Dr. C. E. P. Brooks points out, are probably based on times of extreme heat or cold—periods whose reality is proved by records of the trees or rocks.

Some of the most disastrous winters of all time fell on the world between 900 and 800 B.C. So terrible were they that their memory lives still in those sombre Germanic stories of the Twilight of the Gods. They are legends of lands once warm and happy which fell sudden victim to enchantments

and lay for centuries shrouded in snow and icy ghost-mists.

No mere myths are these tales, but bitter memories. The gods that move in them to their frigid doom are the wraiths of men and women; human ancestors overtaken by the frosts. Never, perhaps, in the tragic comedy of man on earth has there been a greater disaster than this catastrophe of climate which smote the earth about 850 B.C.

The previous century had been happy in Europe, but almost nowhere else. The ancient lands of Egypt and Babylon had seen their greatest day. The iron-shod war power of Assyria was yet to rise. The Jewish kings who shook in the too-large shoes of David and Solomon had sunk into the dissensions that were to deliver them into alien captivity. Blond northerners with straight swords and a way with women had fallen on wealthy Greece, to destroy its ancient culture and renew its thinning blood. The philosophers who were to make the memory of Greece eternal were still to be born out of the new blood and the remembered arts. Over in the lowlands of Italy an obscure and feeble tribe, not even quite sure that they were called Latins, had just begun that settlement which was to be Eternal Rome.

Up the broad valley of the Danube, out of those fermenting Mediterranean lands, there had been creeping slowly for three hundred years some inkling of the thing called culture, a little knowledge of the arts of Egypt and Babylon. Brawny forest men had learned about copper in Cyprus, and in Egypt about the raw black metal which turned weak and red if it lay in the weather but held so sharp an edge on a well-hammered sword; knowledge so de-

sirable that after thirty centuries the honored title of Smith still fills nineteen pages of the New York City telephone directory. The Bronze Age was ending; the Iron Age of Central Europe had begun.

The favorite home of those days was perched on stilts out over a lake or stream. Piles were driven into the bottom, timbers fastened on and the platform thus built was paved with clay. Children played in the clay dooryards. To them came home each night bearded, skin-clad hunters, safe behind the water barrier between them and the beasts of the shore. Here the women winnowed grain and pounded it into meal; spun and wove the coarse hair of animals; kept house. It was a rude life, but not a sombre one. Children of the lake villages played with dolls, women took time to make themselves beautiful with bronze pins in their hair, for some of these trinkets have been found. The climate of Europe was milder then than it is now. Food was plentiful, population increased. The blood of these men and women flows in every European race to-day.

On this happy, peaceful folk fell swift, terrible disaster. A wave of cold and wet rolled over Europe like a wave of pestilence. Lakes where the villages stood rose suddenly, froze over. The lake people were driven away. In more northern lands lakes froze solid the year long; snow lay twelve months long in the pastures.

Driven from the north by cold, blond-bearded giants, ancestors of the Vikings, filtered through the forests to slay the dark-haired men of the lakes and take their women. All was wrath, war, death. Frost had banished comfort from a continent. The hard-

ships, the achievements, the deaths of individuals were preserved in the memories of those who survived. They were the stories of Odin, Baldur, Thor, Freya, of Valhalla and the Twilight of the Gods.

Just why the warmth of Europe was thus stricken no one knows with any certainty. Dr. Brooks thinks that the delicate balance of climatic forces was disturbed somehow so that the Arctic Ocean, previously almost free from ice, froze over completely and rather suddenly, upsetting the whole climate of the northern hemisphere. Whatever the cause, the change apparently extended, as usual, to North America, as tree, rock and lake records show.

It cannot yet be told, with certainty, whether the rainy period that filled Searles Lake in California and made it overflow into Death Valley was the same that froze and flooded Europe into the Twilight of the Gods. But it would seem probable.

All over the world are proofs that great changes of climate have destroyed civilization. In the Central American jungles are the ruins of huge cities built by the Mayas, some of them 2,000 years old. The few survivors of that race are virtual savages; their ancestors abandoned thriving cities for no cause that can be guessed except that of climatic catastrophe. In Cambodia, buried in jungle, are the marble ruins of Angkor the Magnificent, where once a million people lived. In the deserts of Central Asia are still other cities buried in the sands. All their stories are the same.

Many scientists see the greater climatic changes as manifestations of the waning of the Great Ice Age. That Ice Age began at least a million years ago and

was divided into four periods during each of which the ice advanced and the continents were deeply covered with ice. In between were the three warm "inter-glacial" periods, when northern Europe and North America may have been as warm as the tropics are now.

The present era is probably part of the retreating stage of the fourth ice advance; the world is probably recovering from that chill and growing warmer. Scientists speculate whether the ice has advanced for the last time or whether in thirty or forty thousand years, the world will see once more the great sheets of ice creep slowly down from the Pole. There is no answer because the reason for the advance of the ice has never been found out.

Chapter 7

THE WEATHER MAN'S JOB

ASIDE from the general desire to know how things work, the average person has little interest in the varied phenomena of weather. Weather happens; not much can be done about it one way or another. Such things as sunspots and Gulf Streams and thousand-year weather cycles are remote and intangible.

But the forecasting of weather is another matter. This is where weather becomes a personal, practical consideration; the sole point of contact between the average citizen and the science of meteorology. So many human affairs are affected, indeed regulated, by weather—even if they are affairs of no greater moment than those concerning comfort—that everybody everywhere always wants to know what the weather is going to be at various times ahead. Crops, shipping, aviation, railroading, a round of golf—to all these things the future of the weather is a prime consideration. Weather forecasting is and always has been of tremendous importance to mankind.

The beginnings of all science happen to be based on this intense interest in weather prediction; for if the word science is taken to mean the purposeful collection and study of data rather than the mere learning of some art such as catching fish or chipping flints, then weather prediction is the oldest scientific inquiry in the world. Weather forecasting is con-

nected by birth with the celestial twins, astronomy and astrology, and if anything may be related un- equally to twins, it is more closely related to the less respectable of the twins, astrology. It was born only a little while after the birth of civilization.

Somewhere in the neighborhood of western India or eastern Persia, probably in a mountain country, the germ of civilization began to sprout. Here people had begun, some eight thousand years ago, to learn the rudiments of agriculture; had domesticated a few animals; lived according to the rules of civil organization of a sort; knew something about metals, and were working at the invention of writing. From this home of the germ of culture, still not precisely located, civilization branched out; apparently first to Babylonia and then to Egypt.

At home in the mountains agriculture was seasonal. Its signs were automatic and inescapable. It took no genius to see that in the spring, when the snow was off the ground, it was time to till the fields and plant the seeds. When the plants had ripened into grain, by autumn, it was evidently time for reaping. Those who farmed the mountain fields needed no almanacs; their duties were set for them by the visible seasons as these rolled around.

Emigrants from the mountains were confronted by very different conditions when they settled on the broad, river-laced plain of Babylonia. It was hot all year round and there was no snow, ever. Instead, the signal for planting was the coming of the spring floods in the rivers, which spread over the fields. Crops planted before the floods would grow. If they were not already planted when the floods came they

would not grow afterward and a year of crops would be missed.

For the first time man needed an almanac. The time of the spring floods had to be predicted. The rise of the rivers was sudden; if the fields were not ready *before* the first signs of the rise, they could not be got ready at all. But there was no almanac.

In those days there was no calendar. There was no year in man's consciousness, nor any of the framework on which modern people stretch the succession of seasons. Spring floods were as much a mystery to Babylonian farmers, as unpredictable then as the fall of a meteorite is now. They were as unforeseen as a Kansas tornado.

But the Babylonians—greenhorns, tenderfoot immigrants though they were—were failures as fools. They knew what they wanted, which was an achievement more startling than the nursers of modern demi-urges may realize. They set out to get what they wanted and one thing was a system of weather forecasting.

The methods of arriving at the knowledge they sought were none too efficient, it must be conceded, but are not unheard of to-day. They appealed to what gods they had and bribed them at the altars. When these deities failed to confide the secrets of the floods, the people invented or adopted new gods and gave them fair trial. Deciding then that perhaps it was not the fault of the gods but of their own poor understanding—as is the way of men with gods—they tried to find the godly language in symbols and omens. Flights of birds, the creeping of insects, pains in the anatomy of kings—these and a million other omens were studied, prayed over and written

down for centuries in the hope that through them spake the gods. All kinds of facts were these omens to the Babylonians, data to be recorded and studied for their probable meaning in much the way that modern meteorologists study the omens of thermometers and barometers and wind gauges. Some of the clay tablets on which omens were recorded survive to this day and may be read by those versed in the Babylonian tongue.

In addition to piles of rubbish thus studied in perfect good faith, the Babylonians chanced upon something more splendid than the grandest pain a king ever had—the regular motions of the heavenly bodies. To modern man it is a matter of course that the places of the stars, sun and moon vary from night to night according to regular laws; that these places can be named in almanacs; that calendars can be compiled, and that with their aid the coming of the third week in June or the first week of spring can be predicted with surety. To the Babylonians this was news, astounding news, a great discovery. It really was a great discovery, one of the greatest ever made by man. It was the beginning of all science, as science admits.

This Babylonian study of the heavenly bodies became astronomy and likewise astrology; for astrology is nothing but the application to human affairs—which man now decides have nothing to do with the stars, despite the ten dollars paid for a horoscope—of rules and ideas which had proved successful in predicting seasons and seasonal weather. Star movements predict the spring floods, said the Babylonian wise men, therefore why can they not predict the King's death or the arrival of ambassadors from

Persia or any other event worth consulting the heavens about?

The idea was reasonable enough; it merely happened to be untrue. Reasonable enough, too, are modern astrologers and their dupes; they merely happen to think no better than Babylonian priests, and have learned nothing in eight thousand years.

So the true part became astronomy and the untrue part survived as astrology, and these activities of the human mind, the beginnings of all science, were inspired by the practical need for weather forecasts. At last, after centuries of soothsaying and divining and general hokum-working, the priests were forced to get busy. Thus they discovered astronomy and in time predicted the floods and seasons quite efficiently. For which they were permitted to live.

Whatever disappointed customers may think of modern weather forecasting, the fact is that the most important part of it is so well done that it is never thought of as being done at all. That part is embodied in the calendar, and its facts are as common knowledge as the fact that potatoes are good to eat and cow's milk good to drink—which facts, incidentally, were no instinctive knowledge, but had to be discovered. Nobody in the northern hemisphere questions the idea that it will be warmer in August than it was in January. Such a forecast, and thousands of others which every one makes without thinking, are owed to the work of the Babylonians who discovered the calendar, and to their successors who perfected it.

Important though such phases of weather forecasting are, a great deal more is expected of the science nowadays. Instead of asking to be told that snow is

more likely in December than it is in August, moderns ask for specific information about the detailed weather of a single day, or about the minor variations of the seasons. Such information is what they need and what they expect to get. And they get it from the governmental weather bureaus instead of from priests.

There are still geniuses who try to fulfill the demands of modern forecasting by the methods of the priest-astronomers—that is, by omens. The results of their divinations, prayers and supplications are scrolled, for the benefit of mankind, in the drugstore almanacs given free with supplies of liniment. Their covers invariably are adorned with a nude gentleman revealing his insides through a neatly torn abdominal housing, and their contents are fully as useful about the house as the opened gentleman would be. The symbolism of this almanac cover traces back to the Babylonians, who named the signs of the Zodiac after human entrails—which also they used as omens. Amateur forecasters by the divination method write many letters to the newspapers and the omens by which they soothsay are the number of skins on a spring onion, the croaking of frogs, the habits of the ground hog and other fearful and wonderful portents.

Real meteorologists are now groping, much as the Babylonian priests did. They are collecting data, making tentative forecasts for a few weeks ahead, trying to pick out the rules which will permit them to make forecasts for longer periods and forecasts that will be more precise and dependable. No doubt there were times when things went hard with the Babylonian weather men; people did not merely

grumble when the predictions missed it on the date of the floods as they do now when the weather man predicts fair weather and spoils a picnic with rain; they needed a new priest immediately.

The motions of the heavenly bodies are now so well known that their journeys may be timed to the second. If as much were known about the motions of the atmosphere the workings of the weather could be predicted with the same accuracy. So accustomed are astronomers to meticulous precision that when the eclipse of the sun a few years ago turned up five seconds late in New York City, there was an endemic astronomical fit all over the place. But that is astronomy, which has had eight thousand years in which to improve. Modern weather science is so new that General Greely, the man who began much of it in America, is still alive. When modern weather science is eight thousand years old it may be able to predict picnic weather as accurately as astronomy predicts eclipses.

Weather forecasting has not, as yet, even the beginning of a method comparable to that of astronomy, which produces the future place of heavenly bodies by mathematical formulas. True, scientists have tried to base long range forecasts on air pressure and temperatures in different parts of the earth and the oceans but they have met with little success. The task now is the compilation of data, for the twofold purpose of making what tentative forecasts are possible and of study which may eventually evolve formulas applicable to like conditions in the future.

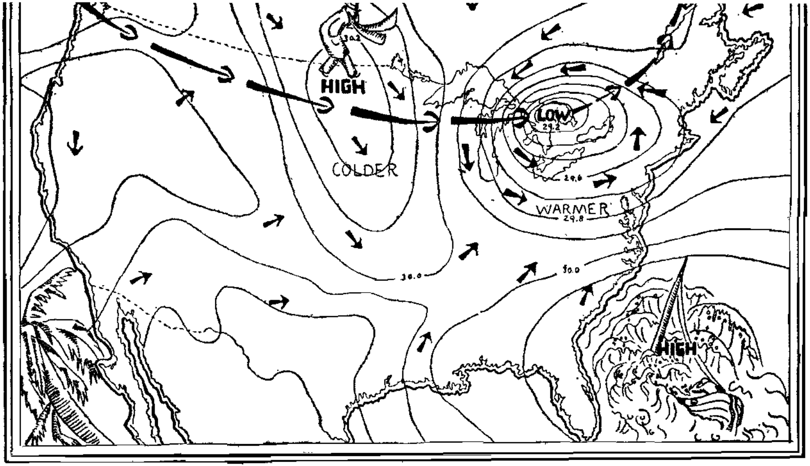
The practical workings of the United States Weather Bureau are based on this policy. A tremendous amount of information about the weather—

the temperature, atmospheric pressure, wind, clouds, precipitation, each measured hour after hour—is collected at some two hundred stations all over the country. The more important details of this information are exchanged by telegraph, so that the official forecaster in Washington and the district officers who make forecasts have presented to them daily a reasonably complete picture of what is happening to the weather in every part of the United States and in much of Canada.

This information is printed as the Daily Weather Map and circulated everywhere. The first edition is issued early in the day from the chief local offices. The second edition, mailed later in the day from Washington, contains more complete information, giving the exact weather status of the country at 8 a.m. on the day of issue.

All of the data on these maps, plus that for previous days and often supplemented by special messages of various kinds, is laid each day before the official whose duty it is to forecast for his particular district. He studies this data, bringing to bear all the experience he has accumulated, identifying the type of condition then current and remembering how such a type of weather usually behaves. Then he makes the best guess he can as to what the weather will do. That guess is his forecast.

There are, of course, many rules and principles and proved probabilities which have been worked out for his guidance. There is, for example, the important fact that weather in the United States largely progresses eastward, along with the cyclonic storms and high-pressure "anti-cyclone" areas. The whole



A PORTRAIT OF ONE OF THE GIANT WHIRLIGIGS THAT MAKE WEATHER FOR THE UNITED STATES.

This is the weather map of April 19, 1928, somewhat simplified. Around the "Low" is a cyclonic storm. The arrows show the whirl. The lines indicate air pressure.

weather picture shifts eastward, like a moving slide in a magic lantern.

As such a slide moves in front of the lantern, clouds, lightning, cows or anything pictured on the slide seems to move across the hung-up screen or across a background of scenery. Just so does the weather picture move across the United States. The atmosphere itself is moving it. The weather in Chicago to-day is apt to be in New York to-morrow; that of Omaha will arrive the day after, and so on. The speed of the weather picture varies; sometimes a bit of weather will move across the whole continent in three days. Again it may take as many as ten days to make the trip.

This movement is obviously of great help in forecasting. Weather at one place to-day will be at another place in a given time, other things being equal. The only trouble is that other things seldom are exactly equal.

For one thing, the pictures blur and change as they move, as though the gelatin on the lantern slide were softening. Storms peter out and disappear. New storms form. Cold waves vanish, hot waves grow hotter or colder. New kinds of weather are being created every hour. Storms may run off the usual track. With man's present incomplete knowledge, to predict what is going to happen in twenty-four hours to all these factors of weather is like predicting the fate of a trainload of women going to a convention: Most of the women will still be on the train a day later, it is safe to say, but where they will be sitting or who will be speaking to whom is something no man can tell.

It is remarkable, really, that the Bureau is so effi-

cient as it is, no matter what lay opinion may think of its picnic-spoiling proclivities. It is a tendency of human nature to forget the good and remember the ill. The times without number that the Bureau guesses right are forgotten so soon as any one is hurt by a bad guess. One of the most unfortunate—although logical—guesses the Bureau ever made was in predicting a good day for the inauguration of President Taft.

The day before that fatal date a typical cyclonic storm, just like thousands of others that regularly sweep across the United States, had passed New York and gone off over the Atlantic. Almost invariably that means the end of the storm so far as this country is concerned. This fact and other conditions made fair weather look *certain* for Washington.

Those were the days when militiamen in their best and gaudiest flocked to Washington for inaugurations and the city was packed. Thousands more of visitors were on trains en route. The time was ripe for a weather trick.

At eleven o'clock of the night before the great day it began to rain. Before morning it was snowing. The snow changed back to rain. By daylight there were eight inches of snow and slush on the ground. Then it rained, snowed and froze by turns. Weeks beforehand the Gridiron Club had issued a joke forecast, predicting rain, snow, cold, heat waves, thunder and lightning for that day. Their forecast proved more accurate than the Bureau's. There was even a thunder shower in the morning.

Washington's supply of rubbers was exhausted. The trains poured visitors into town and people sloshed around in galoshes six sizes too large, tied

on with string. There were thousands of cases of pneumonia. It was the worst possible weather at the worst possible time. The Chief of the Weather Bureau *hid out for months and* Bureau *men* still wriggle when the date is mentioned.

What happened was simple but unpredictable. The storm turned back. It happened to return across the continent going westward—something almost unheard of—at about the latitude of Washington. Its conflict with warm air currents from other directions caused the downfall of the Bureau. No one knows why it came back. It was just one of those things that can happen to a forecaster; the sort of thing that neither he nor his clients ever forgets.

With hundreds of such accidents to contend with, it is easy to see why weather forecasts are not always accurate. But there are certain special forecasts which the United States Weather Bureau has learned to make with precision. One of these, and an important one, is the prediction of hurricanes. For a long time there has been no Atlantic hurricane which the Bureau did not know about sufficiently ahead of time to issue storm warnings. The Bureau's service of storm warnings is of great practical value to shipping along the coasts. Another thing that is forecast with accuracy is the amount of snow which a coming storm will let fall. To a big city snow is a real misfortune. Plans must be made in advance to get it off the streets or it will tie up traffic. An inch or two of snow does not matter, but eight or ten inches, catching the city unaware, will stall traffic and remain for a long time before it goes.

Another important forecast, to fruit countries such as California and Florida, is that of cold waves. To

the Weather Bureau such waves of cold are fairly simple phenomena to predict and usually the fruit growers are warned in time to get stoves and smoke pots ready for the groves.

Many people have wondered, no doubt, what is the record for the Weather Bureau in right and wrong predictions. It would be almost impossible to compile such a batting average; a weather forecast is of necessity such an indefinite thing that in most instances it is a matter of opinion whether it turns out right or not. Undoubtedly the forecasts are right enough, on the whole, to be useful, and just as surely they are not accurate enough to be absolutely depended on, and will not be until more is known about meteorology. A great deal of data must still be collected.

It is just this collection of data that is really the more important duty of the Weather Bureau, and that duty is well done. The data now being collected will form, some day, the materials from which forecasting theories and rules can be formulated. Weather Bureau men are collecting figures now that are still meaningless, just as the Babylonians collected figures of star observations which remained meaningless for centuries.

All over the world weather data are collected and forecasts are made in much the same way as in the United States. Perhaps the weather in Europe is a little better known than it is elsewhere. If that is true there are two reasons for it: European weather is simpler and it has been studied longer, for European weather data was collected by the universities long before the science of meteorology received any attention in America.

Chapter 8

FORECASTS AT HOME

THERE is a broad streak of practicality in human nature that refuses to get very much excited over the subjective, the theoretical, the inanimate, the remote; in brief, over knowledge for its own sake. Knowledge that is not susceptible of direct personal application is rather apt than not to be ignored, or dismissed with the mental gesture that some one else can acquire it and pass on the results. Which is fair enough.

But let it be whispered, ever so softly, that any art or science or craft holds a secret which a man may take over and use for the betterment of his own individual comfort and well being—and he is immediately roused to the point where he may even make an effort to learn something! He will not study the subject, unless he is one of those rare beings who look further than crossword puzzles for their mental exercise, but he will go so far as to get a treatise on the subject and flip the pages until he comes to some predigested wisdom, some recipes which he may apply, with no further meditation, to his own problems. He is looking for something that will be of use to him, and he seeks the royal short cut to it. Which again is not only fair enough but really a lucky break for humanity.

For these reasons it is obvious, and just, that what most people want to know about weather is not the

reasons why low pressure areas induce precipitation or even why Ireland is warmer than Labrador. Such technical facts are subjective and remote; their statement irresistibly invites the reply: What of it?

Out of the whole science of weather, its causes and effects, what most people want to know is: How can they, personally, tell what the weather is going to be like. "Will it rain to-morrow? Very much? All day? How can I tell?" That is the sort of response, if any, that mention of weather science evokes in the minds of most people.

And very nice it would be, indeed, if this book could print a neat set of rules, the painless application of which would make every man his own forecaster. The sales would be almost as great as those of dream-books or guides to perfect etiquette. Not only farmers and shipmasters but ordinary city landlubbers would carry a vest pocket edition or clip out the rules for pasting in hats.

Unfortunately, no such rules can be compiled, to the authors' profound regret. And on second thought, nobody would bother with them very long anyway, for if knowledge of the conduct of the weather could be simplified to such a point, the government would be utilizing it in no time and the governmental weather reports would be infallible.

The fact that the Weather Bureau reports are not infallible is, of course, the reason why so many people would like to do their own forecasting, but the same fact ought to show the same people that there is no short cut to the knowledge they seek. True, one reason for the Weather Bureau's fallibility is the unfortunate circumstance that the Bureau forecasters have large districts to cover; the amateur can confine

his efforts at weather prophecy to his immediate neighborhood. But the chief reason why official forecasts are not perfect in their accuracy is because there are so many things that can change weather that they have not yet been collected and studied to the point where they can be codified.

So there is no hope extended here to him who thinks that by doing a little reading he can beat government meteorologists at their own game.

Any one, however, can be weatherwise; can learn to predict next day's or next week's weather with an accuracy that will prove surprising, can sometimes even make a better guess than the Weather Bureau's district forecaster. Any one can do this, but it will take study and a lot of it.

Happily, such study is of weather itself more than of books. There are, to be sure, certain broad principles to be acquired by reading books, which should make the climb to the grade of amateur forecaster much easier. But the best way to get weatherwise is to live with the weather, to watch it and record its doings. It is the best way and the most interesting —a habit easy to acquire and a habit that grows on one until it becomes a hobby. If this book proves provocative enough to give only a few people the pleasure of living with the weather it will have justified its existence.

The truth is that people used to be better weather prophets than they are now. Probably the necessity was greater; more people lived by and on the weather then than now. Whatever the cause, there were sailors and farmers and woodsmen who could cast an eye on the clouds and guess right three times out of four what the next day's weather would be. As

proof of the statement that people in general were pretty good weather prophets, the vast number of saws and adages about weather may be cited. Most of these sayings are not true any more; that is, they were true for the place where they were coined but as soon as their local truth was recognized they spread and hence became untrue for other places.

Therein lies the clue to the sad fact that simple and infallible rules of weather prediction cannot be formulated: there would have to be a different set of rules for every few miles of territory.

The locally weatherwise, it might be thought, would have passed on their wisdom so that each locality would by now have set up in the public square, alongside the soldier with the baggy iron pants, a table of weather instructions for the guidance of all the citizenry. But not only were local seers jealous of their knowledge. The truth is that in most cases they themselves did not know how they did the trick! The farmhand, the bosun, the fisherman who could take a squint at the heavens and call the turn on the future weather, went through a certain number of mental processes before arriving at his conclusion, but he was not conscious of them. He was weatherwise almost by instinct; he had weather sense.

About weather he was like the blacksmith who never heard of metallurgy but who could temper iron because he knew by the look of it when it was hot enough. He was like the cook who never used recipes or measures, the ball player who can hit a curve. A real appreciation of the scientific facts lies back of all such skill, but it is an unconscious appreciation. Babe Ruth would be annoyed if he were called an expert in inertias and trajectories; which he

is, unconsciously. The world is full of examples of such special skill: pearl and racehorse judging, tea tasting, automobile and airplane driving.

All these are special skills unconsciously exercised. But it should be repeated that behind them all is a knowledge or at least a recognition of the scientific factors of each skill. There is, after all, nothing so very mysterious about these "extra senses."

One of the authors, for example, once knew a foreman of a blast furnace who could tell infallibly when there was the proper amount of lime mixed with the charge of the furnace. Too much lime is a great danger; it stiffens the slag until it will no longer run and the whole works may have to be rebuilt at a cost of perhaps half a million dollars. Chemists are continually testing the amount of lime in the running slag and it is the duty of the youngest chemist in the crew to get up at three in the morning for this chore. The young chemist in question discovered that an old foreman could tell the percentage of lime by merely taking a look at the hot fluid slag as it ran out.

But he had no idea how he could tell. Bribes nor pleading could get an answer from him; he simply didn't know. Spurred on, however, by the discomforts of three a. m., the chemist found out how the foreman could tell. Lime makes slag slightly whiter than its usual reddish yellow color. The differences are too slight for the ordinary eye to see, but by long experience the foreman had given his eye the knack of seeing the minute differences in hue.

And he thought it was a hunch!

The familiar "card sense" is nothing more mysterious. People who lack skill at cards console themselves by believing that they would be more skilful if they possessed a sort of natural endowment that would take the place of long study and practice. But card sense is nothing more than a mathematical, logical turn of mind which has been developed by card playing experience.

So it was with the vaunted weather sense of the old-timers. When they saw in certain months certain cloud formations and when the wind was thus and the temperature so, they knew, *from the unconscious remembering of similar situations,* what was going to happen to to-morrow's weather. There was nothing more to it. Goose bones, rheumatism, hog fat—when they deigned to employ such artificial accessories—were scenery, whether they realized it or not.

One of the bad results springing from the growth of scientific weather observations by governmental officers has been the practical disappearance of the older, unconscious and unscientific method of weather observation. The time will come, of course, when instrumental and rule-determined forecasting will be accurate almost to infallibility—having discovered how the furnace foreman did the trick the chemist invented an instrument that did it better—but there is still room for the old methods of weather forecasting because the scientific perfection is not yet in sight. For the person who wants to make forecasts for his own neighborhood this is especially true.

The way to become a local forecaster is to copy the Weather Bureau's methods on a smaller scale. The Bureau is continually on the lookout. Hour

after hour, day after day the state of the weather everywhere is recorded. From these given facts deductions are drawn. If the deductions prove true, the next time the facts are the same the deduction will be the same. When the deduction proves untrue, the facts on which it was based are studied to see where the error was. Meanwhile new facts are discovered.

The amateur does not need the Weather Bureau's instruments. The old time weather prophets used neither thermometer nor rain gauge. They watched and remembered clouds, winds, rain. The bureau's own instruments are merely necessities for the collecting of data; they help very little in forecasting. Such instruments help scarcely at all in home forecasting.

Weather makes its own signs, for those who will decipher them. And one of the plainest signs is a cloud. One of the first and best things for the amateur forecaster to do is to watch the clouds of his own bit of sky every day, and as many times during the day as he can. Then if he joins to this observation the observation of what happens to the weather —what kinds of causes lead to what kinds of effects —he will soon have a mass of extremely valuable information.

He will, if thorough, keep a weather diary. He will note the time when such and such a character of cloud was observed. He will be particular as to the character of the cloud, too. And he will note other conditions that strike his attention, after he has seen that a mackerel sky does not always bring rain. The mackerel cloud formation meant something, but some other factor entered the question. Was it tem-

perature? Wind? Humidity? Was it the interference of the mountains twenty miles away? Was the air clear? Was the sky red?

Formulating rules as he discovers them, he will notice their exceptions. Studying the exceptions, he will deduce probable reasons for them. By trial and error he will adopt or discard these deductions and so evolve new rules. He can make of it a game that is literally fascinating, and his progress will be sure enough to lend encouragement.

The chief difficulty in the amateur forecaster's path is the slowness and laboriousness of collecting his data. That is why so many short cuts are manufactured, ostensibly to predict the weather, actually just to sell. A few years ago there was quite a vogue for numerous alleged barometers, weather glasses and so on. Few of them were worth wall-space. Some of them are still on sale.

One such swindle consists of a sealed glass tube which contains a liquid. Sometimes the liquid is clear, sometimes it is cloudy. Supposedly the clarity or opacity of the liquid foretells the weather, actually it tells nothing. The tube is just a crude thermometer without a scale; when the temperature is warm the solid content of the liquid is in solution and the liquid is clear; with colder temperature the solids precipitate and the liquid gets cloudy. The tube has no more to say about future weather than the flowers that bloom in the spring.

Another fake is the doll with the cloth skirt which turns pink before wet, cool weather and blue before dry, warm weather—in the advertisements. The doll's skirt is really a hygrometer—an instrument for indicating the amount of moisture in the air.

What the doll hygrometer shows is how much moisture there *is* in the air, not how much there will be.

The marks on the faces of barometers mean little or nothing, either, so far as their arbitrary predictions of "fair, wet, changeable" go. The barometer is an instrument for measuring air pressure. Air pressure is an important factor in weather making, but the barometer can only record the pressure—it cannot combine pressure with other factors and announce an accurate result of the combination. The mercury barometer is a long glass tube sealed at the top; the mercury inside is balanced by the air pressure and therefore varies in height according to the variations in pressure. The aneroid barometer is nothing more than an ordinary steam gauge; it measures air pressure by its effect in squeezing together a small metal tube, usually coiled in a spiral.

When a ship at sea is approaching a cyclone this measurement of air pressure may be, by itself, an important indication of future weather. But to use it on land according to the legends on the instrument's face is plain foolishness. There are too many complications other than air pressure.

There are other alleged short cuts to weather wisdom—instruments, tables, books of rules, charts, gauges and slide rules *ad nauseam.* None is worth a hoot in forecasting, as forecasting. Some of them may be useful in collecting data.

Reliable instruments are, of course, extremely valuable to any one who wants to go into the forecasting game with thoroughness. And unquestionably they add to the fun. There is a fascination about intricate-looking, shiny instruments, as automobile accessory dealers know. The amateur who owns

thermometers, barometers, hygrometers, wind vanes, anemometers—which measure the speed of wind—will enjoy using them and will be led to observe and record more data, perhaps, than he would collect with eye and mind unaided. But he can do without them—and there is a fine joy, too, in the realization of single-handed achievement that more than makes up for the pride of material possession.

The government weather map is an invaluable aid to the amateur forecaster. Whether or not he is equipped with instruments, he should study the weather map each day. His local weather is part of the picture the weather map draws for him. By watching the state of the general weather and drawing inferences from the state of the local weather, he can learn, eventually, what to expect. The weather map is a whole set of instruments working for him constantly and tended by experts.

To get anywhere worth going, the amateur forecaster really must utilize the daily weather map. A red sky at sunset may often, in his neighborhood, mean fair weather. It may mean fair weather almost always if a cyclonic storm has just passed. But if a cyclonic storm is just behind that sunset, it is just as apt to mean rain on the morrow. He cannot tell how near that storm is without the weather map. With it he has a good chance of guessing whether or not the red sky means fair weather or foul—or whether, after all, it means anything.

The person who has the urge and the means to go in for weather forecasting on a thorough scale will maintain a set of weather instruments and read them at regular hours. He will study the weather map daily. He will keep detailed and minute records.

And above all he will record his observation of clouds, air transparency, and so on. He will summarize these data, he will seek the reason when the weather is fickle.

But he will not mistake the means for the end, the technique for the song. He is not forecasting, he is learning to forecast. A blind man uses his cane to feel the way; he does not fancy that the cane chooses the way.

It is like learning people, this game of learning the weather. No book classifications, no phrenology charts, no personnel-directing psychologist can take the place of observation, of day-by-day shoulder-rubbing with assorted humanity—of living with people.

The weather is a puzzle, a detective mystery. Solving the mystery can be more fascinating than guessing the end of a serial story and more profitable. And the chances of success are greater, for writers are tricky and unfair and the weather, after all, plays according to the rules. The rules are there to be read. Living with the weather teaches them.

Chapter 9

LIGHTNING'S MYSTERIES

THE most spectacular phase of weather, thunder and lightning, is one of the least understood. Like meteorology as a whole, it involves physics and chemistry, but it takes into more special consideration an offspring of those two sciences which has become a science in itself—electricity. As a science electricity has grown in topsy-turvy fashion; it is used more efficiently than it is understood; it has been harnessed before the names of its bones have been discovered.

Causes are ordinarily learned after effects are known, but not even all the effects of lightning are understood. As for the causes of its conduct, theories are being evolved and discarded every day. So far as weather is concerned, then, it is unnecessary to touch upon more than a few of the mainly tenable theories regarding lightning, but it is extremely important to present a proper picture of thunder and lightning in their relation to the atmosphere.

The ordinary conception stops with the mental image of a few streaks of brilliant light shooting across a black sky, followed by a crash, a roar and a rumble. Thunderstorms seem to be isolated disturbances, relatively few in number, which somehow spring from clouds.

Potential thunder and lightning, in reality, are always present in every portion of the air. The whole atmosphere of the earth is a huge dynamo, working

all the time so that thunderstorms are always going on. That much is known about them anyway. Exactly what causes atmosphere to produce electricity, what in turn makes lightning of that electricity, and what, again, goes on about a lightning flash to make thunder—all these involve questions still open and bottomless.

Lightning, according to most text books, is merely a vast electric spark, similar to the sparks that the hand can draw from cat fur or rugs in cold weather, and the duplicate of the sparks emitted by the static machine. Like most text book theories, this one is far too simple to mean much. It is true, but it is not enough of the truth.

The sparks are discharges of electricity, as are the flashes of lightning. But then, electricity isn't what it used to be. A generation ago engineers believed that electricity was some mysterious invisible fluid that could flow through wires. It was even spoken of as a current. Then came the vacuum tube and ideas about electricity were changed. The fluid in the wires is an army, not a flood. An electric current is an uncountable number of electrons rushing through a wire. Electricity consists of these invisible particles. Science calls them electrons but no scientist ever expects to see an electron. They are even smaller than the atoms of matter; indeed, it has been shown that electrons help to make up atoms of matter, as they make electricity.

An electric spark is a group of these electrons rushing from one point to another through the air or some other medium. Even in the spark from a cat's back there are billions of electrons. A flash of lightning is also a group of electrons rushing across the

air. To that extent the text book theories are correct, but not much beyond it. Enough has been learned about lightning to prove that it is not simply a discharge of electric sparks.

Electric sparks take, in general, the path of least resistance through the air. In a few cases, especially where the flight of the sparks is short, this path of least resistance is a straight line. But longer sparks from static machines, and flashes of lightning are bent and twisted and wavy. Stereoscopic photographs taken by the Westinghouse Electric and Manufacturing Company with high speed motion picture cameras capable of taking a picture in one twenty-thousandth of a second, show that many lightning flashes are corkscrew-shaped. Similar shapes may be observed in the rush of smaller sparks between the points of a static machine.

It might be thought that the crookedness of the path followed by electric sparks disproves the statement that they follow the line of least resistance. But the air is not uniform. Parts of it have a higher resistance to electricity than have other portions. The theory that these differences explain the twisted path of lightning was advanced several years ago by Sir Oliver Lodge and is still held.

But this is not complete enough to explain lightning, for it is obvious that something much more complicated happens when lightning is in operation. Dr. N. E. Dorsey of Washington, D. C., writing in the Government's Monthly Weather Review, tells of his study of a tulip tree struck by lightning and of the conclusions he draws from it.

This tree was most peculiarly split and shredded lengthwise. A branch was broken off squarely, some

distance above the ground. "Herein seems to lie the explanation of the square break," Dr. Dorsey writes. "In its rush up the fibers, the shredding agent encountered the overhanging and somewhat cupped fibers above the branch, and was unable to penetrate them transversely with sufficient freedom to prevent the stresses from becoming greater than the tree could stand, even though most of the agent continued along the fibers, around the bend, and upwards.

"What was the agent that produced this shredding? The orthodox answer seems to be: Steam or other gases, liberated by the passage of an electric current through the tree. But to me this is not satisfactory; it seems to me improbable that steam or other gas could primarily have been responsible for all of the effects observed. I am of the opinion that in this case the lightning stroke consisted of something analogous to an intense, high speed beam of cathode rays, which planted in the trunk, at the depth of the shredded column, a large number of electrons. Their mutual repulsion, when their onward velocity was arrested, urged them in all directions; but having become attached to the molecules forming the contents and walls of the cells, they were unable to penetrate the fibers in a lateral direction, although they could travel with moderate freedom along the fibers, in the direction of the flow of the sap. Hence they travelled along the fibers, shredding them as they went; being unable to penetrate the fibers transversely, the tree was split, and the branch was broken squarely and pulled from the trunk."

Dr. Dorsey thus furnishes an explanation of the exceptional lightning stroke, the one which ignores

lightning rods and man's ideas of what its conduct should be like.

Such exceptional strokes consist, Dr. Dorsey thinks, not of ordinary electric sparks, but of actual darts or arrows of electrons, moving with tremendous velocities and possessing the same enormous momentum which any kind of material projectile possesses. The doctor returns, indeed, to the time-honored idea of the thunderbolt. Jove and Thor were supposed to hurl material objects at the unlucky men who had aroused their anger.

Dr. Dorsey glimpses no gods behind his darting electrons, but he does see these thunderbolts as bits of matter hurled with inconceivable violence against anything that happens to be in the way. For the electrons which Dr. Dorsey imagines to constitute his darts of lightning are tiny particles of matter as well as being tiny particles of electricity. A dart of them has weight and momentum. It behaves just as Thor's hammer would behave if it were thrown with enormous velocity and if it were highly charged with electricity.

This is a wide departure from previous theories of lightning, the theories which go back in all essentials to Benjamin Franklin and which consider lightning as merely a big spark.

The difference between this dart theory of the lightning flash and the older spark theory of the same phenomenon is that the dart will not follow the laws for an electric current. These laws require that all flashes within a certain distance roundabout should strike on a tall lightning rod, not on anything lower. The same laws require that the flash strike

the highest object in the immediate neighborhood, whatever it may be, not on any lower object.

To Dr. Dorsey's darts of electrons these laws do not apply. The darts can strike anywhere. One of them will hit anything that happens to be in the line on which it originally started. No orange eater needs to be told that squirting juice may strike anywhere, usually on the most embarrassing spot in sight. The darts of lightning would do the same.

A common length for a lightning flash is half a mile. Some that have been studied are believed to have been over five miles long. A single flash of lightning has been estimated at the enormous figure of 100,000,000 volts, nearly a million times the voltage used in ordinary house wiring. House wiring, with its feeble little voltage of 110 or 115 volts, is capable of giving a very annoying shock. Think of a shock about one million times as strong; that will give some faint idea of what a lightning stroke might feel like.

The enormous intensity of the discharges in a lightning flash is even better appreciated from consideration of the power in it. Lightning flashes vary widely, of course, in the power that they transmit and probably also in the voltage that is behind them. It is probably not unusual for a flash to carry power at the rate of 50,000,000 kilowatts, which is about twice the total power-generating capacity of all the powerhouses in the United States. If all the sparks that could be drawn from all the dynamos in the United States were put together it would make only a half-size flash of lightning.

Still more startling figures emerge from an estimate of the total energy discharged by lightning all

over the world. Thunderstorm statistics compiled by the British Air Ministry indicate that the average number of thunderstorms in progress at every one instant in all parts of the world reaches the large total of 1,800. Somewhere in the world nearly two thousand separate thunderstorms are going all the time and that average number will never decrease, day or night or year after year. The number of separate lightning flashes occurring over all parts of the earth is estimated as about one hundred a second. If all the dynamos in the United States combined into a joint electric flash two hundred times each second, they would produce about the same amount of energy which nature wastes day and night in lightning.

In the usual electrical units this continual energy of lightning amounts to something like a billion kilowatts—more than twenty times as much electric power as is used by man in all the world. At average prices this wasted energy would be worth more than a million dollars a minute. Every time an ordinary thunder storm drifts over an American city $30,000 or $40,000 worth of electricity goes to waste. If it were possible to construct some kind of celestial airplane and fly up outside the atmosphere until one could look at the whole earth it would seem to be dotted all over with continual little sparks. These sparks would be the flashes from the 900-odd thunder storms which one-half of the earth is always enjoying.

These calculations are based on the idea that lightning flashes are like other sparks of electricity, except that they are larger, an idea which is probably true enough so far as the voltage, power and similar char-

acteristics of the flashes are concerned. Where the similarity to ordinary electric sparks breaks down is in the path which the lightning flash follows.

Sparks travel along the line of least opposition. A lightning rod, for example, is a conducting path for the current, which means that it is a relatively easy path. If a spark drops from a cloud overhead onto a house equipped with a lightning rod, electrical theory indicates that the spark will hit the rod rather than the house and will follow the rod harmlessly into the ground. That this theory works part of the time is indicated by the fact that lightning flashes frequently do strike lightning rods, especially on the tops of very tall buildings, and do follow these rods into the ground without doing any damage.

The trouble is that not all the flashes do this. Lightning has been known to avoid the tall towers which it usually seeks, whether they were with or without lightning rods, and to hit other and lower objects near by. It is difficult to explain such actions on the usual spark theory. To help in doing this, as well as to explain some other mysterious freaks of the strokes, Dr. Dorsey elaborated his new theory of the electron darts.

Dr. Dorsey's explanation of lightning is not the only one in recent years. It has been suggested that lightning follows a path fixed by a wave of ultraviolet rays which precedes it, the ultraviolet ray serving to electrify the air in advance. And there are still other theories. Different explanations may hold good for different kinds of lightning but there are probably varieties which have not even been identified, much less explained.

One of the eternal arguments between scientists

and mountaineers concerns the phenomenon of "ball lightning." Every once in a while, especially in the mountains, a rounded globule of liquid fire appears during a thunderstorm and moves through the air with about the speed of a thrown baseball—a very slow speed for lightning. The ball of lightning may be only a few inches in diameter or it may measure several feet. After a few seconds it usually is described as bursting—at any rate, it disappears with an explosive report. There have been so many descriptions of this ball lightning that it must be considered as an actual phenomenon. It happens, however, that no scientific expert on lightning has ever seen it. Its cause remains a mystery and no very plausible explanation has been offered. It is something that any chance observer should be particular to watch with great care, for his observations may be of help in advancing science over this stumblingblock.

The so-called "rocket lightning" is another mysterious variety, even the existence of which has been questioned. Instead of moving with the instantaneous speed of the ordinary flash, the rocket variety seems to sail slowly through the air. It is easy to say that this is merely an optical illusion, as some scientists have asserted, but too many good observers have reported it for this explanation to hold. Conceivably it may be a variety intermediate between the ordinary flash and the ball lightning. It too should be carefully watched by observers fortunate enough to see it.

Theories as to where the enormous amount of electricity in lightning comes from must run into the hundreds. The prevalent idea is that it comes from the separation and condensation of water drops in the

air, but this theory is based on premises which are still in dispute.

Steam, it is known, can produce electric charges when it is discharged into the air and allowed to condense. Electric generators have been constructed on this principle. Before dynamos were invented some physicists believed that this might form a basis for practical production of electricity. When moist air is condensed into fog by cooling, or when water is sprayed from a nozzle, charges of electricity may be produced. Dusty air blown around a room will produce small electric charges, which fact probably accounts for the electric flashes observed during desert dust storms.

But about all that these facts prove is that suspended particles of water or dust tend, somehow, to become electrified. Some physicists imagine that this is brought about by friction, which seems doubtful. Others think that the breaking in two of the particles generates the electricity. In plain truth, nobody knows. At this late date, then, two of the most important fundamentals of the phenomena of lightning remain unknown: Why the flashes follow their peculiar paths; where the electricity comes from.

In a mountain valley of the Tyrol a group of German engineers has been at work trying to repeat, on a much larger scale, Benjamin Franklin's experiment with the kite. They have strung a cable across the valley between two mountains. Other cable connections to the ground permit the collection of electricity from the storms which encounter the main cable. Thus data on the voltage and amperage of the thun-

derstorms are being collected. If this experiment is continued long enough it will probably yield more information about the nature of lightning than anything done so far.

The dreaded collision of lightning with buildings and people is really not its more important practical effect, for when it is realized that lightning is continually discharging into the air its collision damage is relatively small. The real havoc wrought by the electricity of thunderstorms is that which burns out millions of dollars worth of electrical equipment every year.

A thunderstorm is much like an enormous broadcasting station and thunderstorms are responsible, as every radio listener knows, for what is called static. Most of the clicks, crashes, whispers and other noises which are picked up and amplified by sensitive radio receivers are really electric waves sent out by the discharge of lightning flashes. These waves are sometimes powerful enough to do serious harm. In telephone and electric power wires they produce "surges" of electricity. These surges, it is true, last only a fraction of a second but they burn out the equipment. So devastating are the effects of thunderstorms that the electrical industry now equips itself with what are called "lightning arresters," which are not devices to stop lightning but rather to let it get away.

Fires and explosions are frequently caused by lightning which does not actually strike the building that is burned. Explosives stored in metal cans are sometimes so placed that sparks can jump between them, and thus a storm anywhere in the neighborhood may set off the whole magazine. It does

not take a stroke of lightning to do this. The effect may be produced by "induction"—just as the dangerous electric surges are produced on power wires.

So important are these indirect effects of the electric waves which lightning produces that the big companies in the electrical industry have undertaken comprehensive studies of the whole matter. The Westinghouse Electric and Manufacturing Company has picked out one of the worst thunderstorm regions known, a spot in the Tennessee mountains where thunderstorms average twenty each summer month, and has sent there a crew of engineers, armed with cameras and with the most modern electrical measuring devices, to spend the summer living with thunder and lightning. One of the most interesting of their instruments is an oscillograph which automatically records any sort of electrical discharge, from a flash of one hundred million volts half a mile long to a spark lasting one ten-millionth of a second, which is the time a high-powered rifle bullet takes to travel the thickness of two hairs.

In all this discussion of the mystery of lightning only the actual discharge of electricity has been dealt with. This discharge in itself is completely invisible and almost completely inaudible. The visible and audible effects of a thunderstorm are the lightning and thunder. They are not primarily electrical effects at all; they are secondary effects caused by the air.

All visible light is produced, it is believed, by the re-combination of atoms which have been split apart. When iron is heated red hot, for example, the heat causes the continuous fracturing of a number of atoms of iron. The fractured atoms, because of their in-

ternal attractions, rebuild themselves promptly and it is this rebuilding process which produces the red glow of light.

In the air the atoms disrupted by the electric discharge rebuild themselves and emit the light seen as a streak of lightning. Through a spectroscope the flashes show the same brilliant lines of light which are given out when air is heated or electrified or when in any other way air atoms are disrupted and allowed to recombine.

"Pink" or "rose" lightning is explained by this fact. For a long time scientists denied the existence of such rosy lightning, insisting that all lightning is white or bluish—which, indeed, most of it is. It has been proved, however, that there is such a thing as pink lightning and that it owes its color to millions of atoms of hydrogen supplied in the path of the flash by the decomposition of water vapor. On disruption these hydrogen atoms recombine to emit a pinkish light. Atoms of oxygen recombining after disruption emit the usual bluish or white light.

The lightning rod, for a good many years, has been widely used as a simple and practical device for steering lightning safely into the ground instead of letting it collide with houses, which it might shatter or burn. All this while the rod has been successful. And in general the reasons why it accomplishes its purpose are understood.

Franklin believed that the utility of the lightning rod that he invented was to attract the lightning flashes, so that these could be carried harmlessly into the earth through the metallic rods connecting with the lightning rod itself.

That sometimes happens, but it is not now be-

lieved to be the chief function of the rods. Lightning rods are chiefly useful, not because they attract the flashes, but because they direct them elsewhere.

The cause of lightning being too great an accumulation of electrons, if in any manner the excess electrons can be led away or disposed of the lightning flash will not occur. The real duty of the lightning rod is to lead away and dispose of the excess electric charge.

In the final analysis there is only one way to dispose of excess electrons. That is to let them combine with the other electric particles called protons. The electrons are negative, the protons are positive. Negative and positive, as always, neutralize each other.

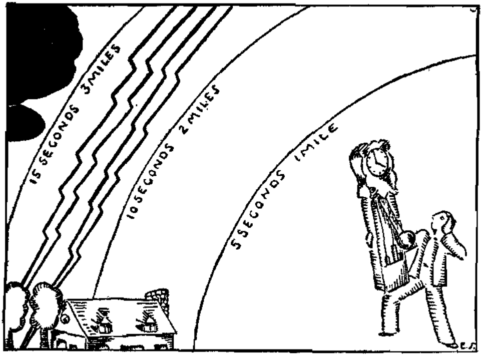
It happens to be one of the habits of the negative electrons and likewise of the positive protons to escape with unusual ease from pointed things. This tendency of electric charges to escape from sharp points is the real secret of the lightning rod. Charges accumulated on the clouds are matched by opposite charges on the ground, on trees, on buildings and other objects. These ground charges rush up into the lightning rods and escape into the air. Thus they combine with and neutralize a part of the charges on the clouds. A flash in that immediate neighborhood is made less likely. The frameworks of steel skyscrapers are believed to serve in somewhat this same way, to relieve excess electric charges on the ground during lightning storms and thus to protect the persons housed within them.

For the wayfarer who finds himself caught in a thunderstorm far from shelter there is but one thing worth remembering. That is that lightning is more

apt to strike lofty objects, like steeples or trees, than to strike the ground itself. If a person is the loftiest object in sight, as a man might be when walking on a level plain, the lightning is not unlikely to select him. Travellers caught on mountain tops in the tremendous thunder storms which sometimes sweep over such places, have been known to save themselves by lying flat on the ground.

The comparatively dry space underneath a tree, naturally sought by persons caught out of doors in a thunderstorm, is made unduly dangerous by the tree itself, for trees are among the kinds of things that flashes love to strike. Regardless of wet, the safest place in a thunderstorm is at some little distance from trees, flag poles and other lofty objects, but with enough such things not far away so that the traveller himself is not the loftiest object in the neighborhood. Inside houses or other buildings the best thing to do about lightning is to forget it. The superstition that open windows attract the flashes has no known basis in fact, nor is there any reason to believe that one is safer in a bed or under it than going unconcernedly about his business.

Even the thunder, the harmless, useless, unimportant part of the lightning phenomena, remains mysterious in some of its aspects. The old idea, still expounded by many textbooks, is that the noise is caused by the expansion of air along the path of the lightning and the subsequent coming together of the expanded portions to fill up the vacuum. The word "clap" as applied to thunder is peculiarly appropriate for this is much what happens when one claps one's hands. Much the same thing causes the noise when a gun is fired.



ONE WAY TO BE SURE YOU ARE SAFE IN A THUNDERSTORM.

Most people who fear thunderstorms fear thunder, which is harmless, more than they do lightning. Terrifying though it may be, thunder serves to show, roughly, how far away is the lightning flash that precedes it. A flash of lightning is seen, of course, at the speed of light, or 186,284 miles per second. The speed of sound, on the other hand, is merely one to two thousand feet per second, depending on atmospheric conditions. The artist has worked out this problem in long division, and shows herewith a simple method to tell how far away is the lightning flash and the storm that produced it. For each five seconds that the clock ticks between the instant when you see the flash of lightning and the time when you hear the thunder the storm is one mile away. When you hear the thunder the danger is over—from that flash. This is the *only use that thunder is to anybody.*

What studies of thunder have been made recently —and there have been lamentably few—indicate that this theory is much too simple, but what actually happens is still unknown. The roar and rumble that follow the crash of thunder are merely echoes, sound waves reflected from the surfaces of clouds or back and forth between the earth and clouds or even from mountains or buildings.

Useless though it is, thunder serves to show roughly how far away is its preceding lightning flash. The speed with which one sees a lightning flash, which is the speed of light, is 186,284 miles per second. The speed of sound in the air is 1,000 to 1,200 feet a second; depending on the temperature, the air pressure and other conditions. Simple mathematical division indicates that a thunderstorm is about one mile distant for every five seconds between the instant its flash is seen and the instant the thunder is heard. Since the flash may be a mile long and since sound waves do not always travel in straight lines through the air, this rule gives only an approximate answer.

Chapter 10

SNOWFLAKES AND BLIZZARDS

TO any one who has confined his contact with snow to shovelling or wading or cursing—or even to coasting—the first close sight of a snowflake is sure to bring astonishment. A snowflake is not merely a feathery piece of ice that melts into water on the cheek; it is a miniature design as truly ruled, as symmetrically assembled, as consciously ornamented as though a skilled draftsman with more than a touch of genius had worked over it for days. It is no unit of another design, no sketch for a more fully-fashioned graphic idea, it is complete in itself with all the elements of the finished work; an entity of art.

Nor is it the embodiment of one or even a hundred ideas of design. One snowflake never duplicates another's pattern. According to the laws by which it is made, a snowflake a quarter of an inch wide may assume any one of a number of possible forms, running into billions of billions. That inconceivable number of designs is being made day after day, somewhere in the heavens.

Except that snow is more or less a frozen cloud, little is known about how a snowflake is formed. What little is known has been learned from the peculiar beauties of its form—beauties that have attracted artists and naturalists for centuries. Snowflakes are

among the few things in weather science that carry clues to their origin openly with them, yet those clues have not been followed to their end. Only the general fact is known about them: they are crystals of water, because only crystals can have the shapes that snowflakes assume.

There is little use attempting to describe the exquisite crystalline forms of snowflakes; besides, they have been made familiar to most readers through photographs. Here and there about the world are gentle souls so enthusiastic over the beauty of snowflakes that they spend all their winter days photographing them and their summers comparing, cataloguing and exchanging rare specimens.

Foremost in America, indeed an authority of world-wide renown, is Mr. Wilson A. Bentley of Jericho, Vermont. He has spent more than forty years photographing catches of flakes from every snowfall in his wintry home and has formed a collection of some 5,000 unduplicated crystal designs. So obviously in love with his treasures is Mr. Bentley that even in the staid pages of the Government's Monthly Weather Review his words glow with a warmth unfortunately foreign to meteorological writing. His enthusiasm has led hosts of others to seek for themselves the gems lavished on earth by the skies.

Mr. Bentley uses a blackboard on which to catch and photograph his specimens, but a piece of rough black cloth with a nap on it, such as velvet, will do admirably well. It is quite possible to see with the unaided eye the strikingly varied designs of the flakes. When their symmetry has been fully realized, it will seem impossible for so many distinctly different patterns to be formed, yet it is said that

more than one hundred thousand separate flake forms have been recorded.

All the designs are based on the same fundamental symmetry. The flakes are crystals of water, equivalent to crystals of rock candy or quartz or diamond. Familiarly, matter is described as existing in three states: solid, liquid and gaseous. There must be added a fourth state—a variant of the solid called a crystal. Not all materials exist in this fourth state. Glass is a solid, according to the usual definition, and there is nothing crystalline in glass, despite the ordinary use of the word crystal to mean glass. That commonplace metaphor refers to the fact that ideally glass looks like rock crystal, which is scientifically a true crystal, and when glass was first made, rock crystal was the model for imitation.

In glass the atoms of its constituent elements are arranged more or less haphazard. In a crystal, whether of rock crystal or diamond or anything else, the atoms are arranged in rows and ranks, each atom in place to make a design. It is as though some atomic top sergeant had mustered his company and brought each soldier to attention.

Just that happens when a substance crystallizes. Its atoms snap into their places, specified by the character of the substance; count off, dress the line, form squads. By this exact placing of the atoms chemists and mineralogists can identify substances. The shape of a diamond or of a crystal of pyrite—fool's gold—is almost as good a diagnostic of what it is as a chemical analysis would be.

The secret of gem cutting is based on this internal nature of the crystal. The cutter grinds faces on the gem that will fit the internal structure in such fashion as will make the best display. The passage

of light rays through the crystal, its conduction of heat, and its other properties depend on its internal structure; that is, on its arrangement of atoms.

A snowflake, then, is a crystal of water, with its atoms in place according to the arrangement peculiar to crystalline formations of that substance. But usually a snowflake is only part of a crystal, the skeleton of a crystal in process of formation. It is equivalent to the steel framework of a modern building. First Nature throws out a series of girders, to show what the structure of the water crystal is to be. This series of girders is gradually filled in. Flakes that reach earth are seldom complete, so that instead of being a solid crystal like a mineral they remain lacy, delicate frames which would, if given a chance, have become complete solid water crystals.

Crystals of solid water can be prepared in laboratories. They are ice, but a peculiar kind of ice. Ordinary ice is made up of water crystals but usually these are small and mixed inextricably together. The water froze too rapidly and was disturbed in the freezing, thus altering the regular growth and formation of the crystals. In Nature about the only place where water gets a chance even to begin to crystallize undisturbed is in a snowflake.

The crystalline formation of snowflakes is what gives away the chief secret of their origin. If it were not for that formation it might be thought that snow is frozen rain. But frozen rain is hail and hail is like ice, not snow. When a raindrop freezes in the air the suddenness of its cooling prevents the growth of real crystals. These may exist, all mixed up inside the hailstone, but they never develop the forms which they assume in snow.

It will be seen from this that snowflakes must

form quite slowly, as compared with other weather phenomena, and that they must have a lot of free space around them to form in—a drill field not cluttered up with flagpoles and cannons and spectators. They have time and space, these water atoms, to take their places properly; they are not jammed together suddenly like passengers in a subway.

Snow can form, probably, in two ways; by the freezing of a thin cloud or fog, or by the direct freezing of water vapor out of the air. These possibilities lead, as so often happens, to phenomena that are familiar but that lack completely satisfactory explanations.

When phenomena seem easy of explanation a plausible theory may be devised, accepted and retained; to the ultimate handicapping of weather science, for the discovery of error in the theories becomes a mere matter of chance and not of purposeful speculation. Men have long said, for example, that when moist air is chilled sufficiently to freeze the water out of it, snow is formed. Quite true, but they neglected to inquire why the water freezes as snow, and not as water and then hail. Dozens of other inconvenient questions about snow might be asked by any scientist, and weather experts could not answer.

The truth is that the details of why snow forms are not known. It is conceivable, even probable, that some rain really forms as snow and that the flakes melt on their way to the earth. Something determines the form that frozen-out water will take; whether fog, rain, snow or hail. The chances are that this dictator of form is a combination of the rate of cooling and the temperature at which the cooling

eventually arrives; both modified by the amount of moisture in the air.

The study of snowflakes by such an artist as Mr. Bentley is worth while, of course, if only for the sake of the beauty which is pursued. But not that alone; it promises to become a highly practical and important branch of science. This is because the design of the flake undoubtedly is an indication of the conditions under which it was produced high in the air. The temperature of the air where it was formed, the rate of cooling, the nucleus around which the first minute drop of water condensed; all these things unquestionably leave their marks on each flake. Some day experts in ice crystals will read the conditions of the upper air from these marks just as geologists read the conditions of past ages from fossils in the rocks.

Nothing much has been read so far from records graven on the flakes. Even though thousands of different designs have been collected, there is still too little known about the types and shapes that can be formed. Nor is anything known of the conditions that determine these variations in form. This lack of knowledge is because no man has ever made a snowflake or a raindrop. Laboratories should set up refrigerators where snowflakes can be made under controlled conditions. This research, incidentally, would be an excellent line for an enthusiastic amateur to take up. He would have the field pretty much to himself and almost anything he achieved would be his own original discovery.

Refrigerators and the artificial production of snowflakes are, of course, beyond the means of most persons, but no amateur need deny himself the thrill of

studying the question for that reason. Observation of a winter's snowflakes is free, and is emphatically a valuable work from any point of view. Too many different forms cannot be collected, and it is important to note, also, what were the conditions of the weather when they arrived.

One thing especially needs doing and only a few patient workers have succeeded in doing it, or perhaps too few have tried. That is the study of the internal nature of the flakes under a powerful microscope. Such study is difficult because the heat of the metal parts of the instrument, warmed by the hand, melts the flakes. It would be highly desirable to know, from observations of a great many specimens, what kinds of solid particles serve as the nuclei of the flakes; for it is probable that snowflakes resemble raindrops in needing something to begin their condensing on. Science needs to know, too, whether there is always a speck of non-crystal water, ordinary ice; which would tend to prove that the flakes form first as water drops. Many other microscopic details would give valuable clues to the whole problem.

Pitifully academic must seem such queries to a reader nurtured on the stunt-science of the front page. To all too many alleged intelligences no knowledge that does not directly coin money is worth bothering about—unless, for some mysteriously exceptional reason, it be stunt aviation. It would indubitably amaze and even irritate the possessors of such short-sighted views to be told that the solving of the problems of snowflake formation might do more for aviation than a hundred flights by every pretty girl in the world over every known ocean, with or without reception committees.

Yet that is the truth. The solution of the snowflake problem would probably bring with it accurate knowledge of upper air conditions. By application of its negative side to the manufacture of other water forms such as fog, that present chief obstacle to long-distance aviation might be avoided or overcome. Vaudeville tours, however, are not the lot of snowflake students, nor are they likely to be even when aviators shall have become mere air-chauffeurs.

Whether anything more is ever learned about snow, its value to the world is generally recognized. The vegetation of the temperate zones pretty much owes its life to the blanket of snow that keeps the roots of perennial plants from freezing to death during the winter. Snow keeps the ground warm enough, also, that seeds left over from autumn do not freeze and are ready to start in the spring a new generation of the annual plants.

It is not that the snow itself provides heat, of course, but that its blanketing quality keeps heat from getting away, just as a blanket on a bed keeps in the natural heat of the body. The bed blanket accomplishes this saving of heat because of the air held between its fibers. Air is one of the poorest conductors of heat known. A breeze that cools the body does not conduct the heat away as a piece of cold metal does. It is merely impinging on the body, getting warmed, and passing on to be replaced by new air. The function of the blanket is to prevent the motion of the air, to keep it still so that it will keep heat from getting out.

The snow blanket of the ground acts in precisely this way. The loose structure of the crystals makes the mass highly porous. It holds air which cannot

move. Thus it holds in the heat of the soil or even of human bodies housed beneath it.

Valuable as snow is in keeping plant life warm, it becomes a costly nuisance whenever it falls on cities in great quantities. The American name for a violent, wind-driven snowstorm is blizzard. While these storms differ little from other such storms accompanied by precipitation, the acute discomfort that they occasion has driven blizzards into the public consciousness more than most weather phenomena. The history of any town anywhere usually divides at the date of the Big Wind, and any town in the blizzard areas remembers and takes pride in its year of the Big Blizzard. New York City being a big town, naturally boasts of having had the biggest blizzard. Its date was March 12, 1888, and that is still described by any one old enough to remember it as a special and splendid example of chaos on wheels.

For some time before New York felt sure spring had come, especially since the circus was in town and the papers had begun to list the arrivals at Newport. On the evening of March 11 there was a gentle rain, and it too was hailed as a sure vernal indication. But by next morning winter was back. At midnight the rain turned to sleet and then to snow. In six hours the city was buried. In seven hours Brooklyn Bridge was closed to traffic. One man who succeeded in passing the police lines had to be pulled out of a drift before he got half way across. Two hours afterward all street car traffic had ceased. Cable cars were abandoned where they stopped; horse cars with four horses were left where they stuck. The drivers rode the horses back to the stables leaving passengers marooned inside. One elevated train

made two blocks in six hours and then gave up. Other elevated trains were all stalled before eight o'clock; owners of ladders made fortunes as rescuers at fifty cents per rescue, and the passengers were glad to pay it.

Meanwhile the wind was blowing at a tremendous rate. Some of the few ferry boats that ventured out had their flagstaffs snapped off by the wind. Only thirty of the 1,100 members of the Stock Exchange were present for the opening. A darkness like that of an eclipse overhung the streets and the air was so full of driving flakes that it was almost impossible to see or breathe. Electric wires went down and there were no street lights that night. Drifts rose as high as second story windows.

The city, for the one and only time in its three hundred years of history, was flatly conquered by the weather. For two days it was out of touch with the world. No street cars ran for four days nor could food be delivered. Rail and wire communication was cut off. Normal train service was not restored for ten days. Millions of dollars disappeared in lost business and ruined equipment. Hundreds of thousands more it cost to dig out the streets and railroads.

And it took the snow only six hours to do all this damage!

Just beautiful, myriad-shaped little crystals of water did it; the miniatures that Mr. Bentley studies because they delight his artist's eye; that others, professional and amateur, ought to be studying because they hold, in their beauty, as important secrets as any the heavens hold for man in this mystery of weather that means so much to him.

Chapter 11

SECRETS OF HAIL

IF snow is frozen cloud, hail and sleet are frozen rain. To most people they seem to be much the same and no doubt many people have wondered why there should be two names for one ice-making process. Actually they are distinct phenomena. Even the ice that they form is different. Hail, from the weather point of view, is by far the more important.

Hail is raindrops juggled unusually high in the air. Hail stones are raindrops frozen by the breath of the thunderstorm.

Perhaps the most curious of the many facts about hail is that so few people know these facts, for they are easy to observe. Perhaps the reason is that when the opportunity for learning about hail presents itself the attention is apt to be more concerned with the chances of getting wet or being pelted or with the lady friend's fear of thunder. At any rate, here are some things about hail that not every one knows:

Hail always comes with thundershowers. No thunderstorm, no hail. Even the supposed exceptions are probably not real ones.

Hail nearly always occurs in summer. There are very few records of winter hail anywhere in the world.

It seldom hails at night.

Nearly all hailstones are composed of alternate layers of snow and ice.

Like the curious shapes of snowflakes, these facts

about hail are enough to reveal its entire natural history. The facts have been known for many centuries, yet it has been only twenty years or so that the formation of hail has been really understood. Before then a great many complicated and difficult theories were favored, but the real theory is quite simple.

The essential process in the formation of hail is the same as in that of rain—the vertical circulation of the air. When rain drops are formed the droplets begin their condensation on a nucleus in the cooling air, grow larger as the air rises until they are heavy enough to overcome the rising action and fall against it to the ground. Each raindrop must rise at least once and fall at least once, but some of them may be tossed around still more. In a hailstorm the drops are tossed about more violently.

There are two essentials in which hailstorms differ from ordinary rainstorms. One is the distance to which the rising air currents ascend. The other is the shape and speed of the rising air currents.

To make a hailstorm out of an ordinary rainstorm the air currents must rise relatively high. The critical height, in temperate regions such as the United States, is probably about two miles. Air currents that push this high or higher in a rainstorm are apt to change it into a hailstorm. Cold air is necessary to freeze the raindrops, and in summer air cold enough for this purpose is seldom found at lower altitudes.

Then there must be a small, rapidly rising air current which will play up like the jet of a fountain.

Nowhere except in the typical summer thunderstorm are these two conditions met; that is why

hail falls only in summer and only in thunderstorms. In fact, hail is virtually limited to one part of a thunderstorm—the part immediately behind the advancing front.

Into the heavy, cauliflower-shaped cumulus clouds which herald an approaching thunderstorm—and which are really the tops of rising columns of air—a draft of air rises upward, in front, and rushes downward, in the rear. The updraft blows rather gently against the front of the storm and this has given rise to the saying that a thunderstorm always comes on against the wind. For once a weather adage is universally true. The thunderstorm is sucking up air from the heated land over which it advances and this hot air forms the intense up-draft which really creates the storm.

Just before the rain begins to fall there is a sudden and sometimes violent gust of wind that blows papers and dust about—the blast that makes people say: "Here comes the storm!" This wind is really the down draft, coming from behind the storm and blowing along the ground just ahead of it.

This tumbling motion of the air, circulating vertically in a direction counter to that of the storm, like a hoop rolled with a backspin, is one of the things that make the thunderstorm a special weather phenomenon. Its name is a bit unfortunate, for not thunder distinguishes it so much as this vertical revolution of the air—almost as though it were a cyclone laid on edge—and its relation to lightning is quite unimportant. The rapidity of the air movement merely happens to produce electricity. The typical revolving motion results from the overheating of the ground and the air next to it, and that is why thunder-

storms are frequent in summer and rare at other times.

Rain forms in thunderstorms precisely as it does in any other kind of storm. The updraft in front is cooled by its rise and its water is condensed to form raindrops. The rain is usually intense because the air current rises rapidly and gives up its water quickly.

The fact that these summer showers almost always fall over a small area brings in the second essential characteristic of such storms—the narrow, fountain-shape of the rising jet of air instead of the broader, more wide-spread rise which brings an all-day rain.

A narrow column and a fast rise, then, are characteristic of summer thunderstorms. And they are the essential conditions for a hailstorm. But not every thunderstorm produces hail. The storm may be too small or too slow, or the fountain may not spurt high enough to reach the really cold levels of the upper air. When hail falls, its formation is a continuation of the rain-drop process which is going on inside the clouds. Water has been condensed in small drops on dust particles or ions and the drops are being carried upward, meanwhile collecting more and more water around their cores.

When the rise of air is rapid and strong enough, these drops are swept up and up into the region of eternal frost, and there frozen solid. They are then hailstones, but very small ones. If they were to fall at this stage in their manufacture, they would melt long before they reached the ground. In order to become real, able-bodied hailstones with size and gumption enough to fall and hit somebody they need

to go through another process. They have to be juggled a bit by the storm.

This is where the fountain-shaped rising column of air gets in its work. The air is continually flowing over its sides and falling back or slowing up, just as the water falls back from the sides of a water fountain. Since the air fountain is narrow, the air which falls back from its peak does not escape beyond the area of the storm.

With that falling air comes some of the little hailstones, starting what they fondly hope is a trip to the ground and, with luck, a glorious end against a tender head. Part of the dream comes true for some of them; they fall freely toward the ground but they melt into rain before they get there. They were hailstones once but their luck did not last and they didn't make good. There must be a moral in this somewhere.

Things are different with the less impetuous hailstones that fall from the fountain into the front side of the storm. These fall right into the centre of the rising column of air. And they are carried right back to where they came from.

It is snowing in the higher levels of the storm where they were first frozen, and so they took on there a surface layer of snow. And as they fell, they added to the snow a layer or skin of rain water, for to the cloud they were simply nuclei on which to condense water into raindrops.

When they rise again to the cold upper levels this outer layer of water freezes and another skin of snow is added outside it. As this rise and fall may be repeated many times, a hailstone is made up of these successive layers of snow and ice. If cut through it

will show them in rings like the annual growth-rings of a tree. These hail rings show the history of the hailstone, too, for each pair of ice-plus-snow rings marks one round trip to the top of the storm and back.

In the examination of hailstones for the number of round-trip rings there is a fine chance for the amateur to do something decidedly worth while for meteorology. Scientists have no statistics about this formation of hail; not enough stones have been cut through and examined to show how many trips the average hailstone makes.

The explanation of the formation of hail also shows why it occurs at the very beginning of a storm. Even a severe thunderstorm that is mostly rain is often preceded by a few hailstones. These are stones that have fallen out of the air fountain frontwards, to be lifted again and enlarged; the others have melted ignominiously into rain. The hail is over in a few minutes, for in that short time the storm has swept on and the observer is under the centre or back part of the rising fountain where hail is not formed in appreciable amounts.

And the curious facts about hail are explained, likewise: There is no hail without a thunderstorm because only in such storms does the air rise violently in a fountain-shaped jet. It hails only in summer because only then does the heating of the ground make the air fountain a possibility. There is no hail at night because nightfall cools off the ground and the air next to it. Hailstones are alternate layers of ice and snow because water and snow alternately adhere to the frozen rain droplet that is the core of the whole business.

The stones of an ordinary hailstorm run from an eighth to a half inch in diameter—too small to do much harm. But only too often the stones are of such size and fall in such numbers that they do a vast deal of damage to crops and cattle and buildings and even to human beings.

A single Kansas hailstorm on June 2, 1927, caused a damage to wheat ready for harvesting that was estimated at two million dollars. In the same year 298 hailstorms in the United States caused a loss estimated at $15,000,000. In the wine-growing regions of France, the "grêle," as a hailstorm is locally called, is a continual menace to the fruit and leaves of the vines.

Casualties and deaths among human beings are an infrequent result of hailstorms, but they sometimes occur. In 1928, while the villagers of Klausenburg, Roumania, were celebrating May Day with an open-air feast and dance, hailstones as big as hen's eggs fell suddenly and in great numbers. Every window in the village was broken, roofs were damaged, six children were killed and ten adults seriously injured.

Most of the stories about the maximum size of hailstones are unbelievable. East Indians seem to hold the record, for stories if not for hailstones. Twenty-inch stones are nothing; a stone as big as an elephant is known—to Indian story tellers. And no less a personage than the famous missionary, Father Huc, tells of a hailstone in China that was as large as a *millstone*. Perhaps the Father meant a small mill. The grain of truth, if any, at the bottom of these tales is probably this: that many hail stones froze together on the ground to make the big lump,

HOW HAILSTONES GET FROZEN INSIDE A THUNDERSTORM.

There is a draft of air blowing upward in front of the storm. If raindrops fall into this they are blown up into the icy cold of the upper air. There they freeze and presently fall. But some of them may fall into the updraft again and be tossed back into the refrigerator for another freeze and a second coating of ice. Behind the storm comes a downward blast of air and the rain. Hail comes only with thundershowers. No thunderstorm, no hail. It hails only in summer. It seldom hails at night—probably never. All these rules and regulations about hail are due to the fact that only in a thunderstorm on a summer day are combined the essential conditions for producing hail. To make a hailstorm out of an ordinary rainstorm the air currents must rise relatively high. The cold air necessary to freeze the raindrops is seldom found lower than two miles up, in summer. In winter the water becomes snow before it has time to freeze and refreeze into hailstones. Hailstones as big as baseballs and weighing a pound have been found.

which, after the excitement died down, was found by some one who assumed that it fell as he found it. There may be a moral in this, too.

Hailstones as big as baseballs and weighing from half a pound to more than a pound have fallen in well-authenticated instances. There seems to be nothing to limit their size except the velocity of the upward air fountain. If the action of this air column is extremely violent there is no reason why the beginning stone should not be juggled up and down enough times to produce a final stone a foot in diameter.

Probably the most terrific hail storm in history was that which swept across France and Belgium and into Germany on a very hot day—July 13, 1778. The natives still remember it, after a century and a half.

It began on the slopes of the Pyrenees and ended on the Baltic Coast. Hail fell in two parallel strips, each seven to fifteen miles wide. The hail strips were fifteen miles apart; in between it rained but there was little hail. In the dear money of those days the damage was estimated at a million pounds sterling, the equivalent, nowadays, of fifteen or twenty million dollars. A storm of much the same character started in Burgundy on June 6, 1928, but it happened to begin in the late afternoon and the coming of night stopped it before it could do more than two million dollars' worth of damage.

"Hail regions" are often spoken of—districts where hail is said to be common. There are such regions; the lay of the land makes air currents which are favorable to the creation of updrafts that make

violent thunderstorms. In addition, the topography of hail regions favors the presence of cold air levels that are not too high.

From all this it will be seen that not much mystery is left about the phenomenon of hail. One thing, however, that science has not yet been able to explain is the "hail noise." There may indeed be such a thing; many observers, especially in France, have reported a loud, crashing noise emanating from a hailstorm. Some writers have assumed that the noise proceeded from the hailstones knocking together in the air. This, of course, is not impossible. But no trained observer happens to have heard this noise, and so its reality is somewhat disputed. Any one who hears it should make a phonograph record, but it is perhaps asking too much for the coincidence of a record-making machine and a noisy hailstorm on the same spot at the same time to happen once in a thousand years.

In the short and simple annals of sleet the only difficulty that arises is one of words. In England "sleet" means a mixed fall of snow and rain, or of snow and hail. In the official terminology of the United States Weather Bureau the same word means the occurrence of a rain of small crystals of actual ice. In the ordinary American language "sleet" means the depositing of a coat of ice on trees, wires, etc.,—a happening that spells trouble for fruit growers and electric linemen, and, indeed, for most every one else.

Sleet storms do tremendous damage and there are so many of them in the United States that the telephone companies have found it cheaper in the long run to get their important lines underground.

The formation of the glaze of ice, or sleet, is quite simple. It is rain which has fallen on something colder than the freezing temperature. After a cold night twigs and wires may well be this cold. At the same time there may be a layer of air not far from the ground which is not cold enough to create snow. Rain falling from this stratum of air will freeze into ice the moment it touches the twigs and wires. Indeed, the twigs and wires need not be exposed to very cold air in order to bring about their coating with sleet. On a calm, clear night that is only moderately cold the heat radiates from them, and then, if rain falls in the morning, sleet is produced.

In Europe the ice storm or glaze, as it is usually called, is quite a rare occurrence. A history of English frosts that covers seventeen centuries mentions only one ice storm, that of 1672. In the United States the greatest number of sleet storms occur in a belt stretching from Nebraska, Kansas and Oklahoma to New England and the Middle Atlantic States. But they have, on occasion, visited damage on the Gulf Coasts of Texas and Louisiana, Central Florida, the southern border of Arizona and near Los Angeles.

If no great wind accompanies the sleet little damage is apt to result, beyond a possible stalling of traffic, for the coating of ice is usually so thin that healthy trees and stout poles can carry the extra load. But if the sleet continues, with or without wind, so thick a coating may be formed that its weight breaks everything it clings to. Wires are frequently coated with sleet an inch thick and a three inch thickness is not unknown. Since this sleet is relatively heavier

than the twig or wire which it encases, the additional weight is a serious strain; a tree of average size may be carrying or trying to carry five tons of sleet.

The coating of sleet is one of the most spectacular phenomena of weather, indeed, to those on the inside looking out it seems beautiful. But to the farmer or the electric lineman it is something else: he calls it "white hell."

Chapter 12

THE MENACE OF FOG

LITTLE as man may know about the roots of weather, he has somehow succeeded in conquering almost every enemy aspect of it in one fashion or another. He may not have known the cause but he felt the effect and managed to blunder upon some device that would overcome or temper its unwelcome qualities.

The great exception to that happy list of conquests is fog. Fog remains man's only unconquered enemy among the aspects of weather. Cold has been conquered by houses, fires and clothing. Rain falls harmlessly on roofs and umbrellas. In only the greatest tempests does wind make trouble. Lightning still does harm, but much less than it did for primitive man. But against fog, man can do virtually nothing.

At sea, fog has always been the mariner's chief enemy. The development of devices like fog sirens has made fog less dangerous to shipping. But with the rise of aviation, fog becomes an even more serious danger. Fog is perhaps the chief obstacle to the development of cheap, safe, wide-spread air traffic. It was fog that brought about the long-drawn catastrophe to the Nobile expedition; that almost brought Commander Byrd's transatlantic flight to tragedy.

It is only a gallon or two of water that gives man

all this trouble, that wrecks his ships and airplanes—a gallon or two of water gone wrong. For fog is simply a cloud in the wrong place and there may be scarcely a gallon of water in a cubic mile of it.

A few quarts of water so misplaced tied up the harbor of New York City for forty-eight hours in May, 1928; eight liners collided, twenty or thirty ships were fog-bound. A fog in the estuary of the Thames once kept the harbor of London fog-bound for five days and cost more than five million dollars.

All fogs and clouds are essentially the same thing. They consist of very small drops of water condensed around some sort of nuclei; drops that do not grow big enough to become rain because there is not enough vertical circulation of the air.

The density of a fog or cloud is fixed by the sizes of the water particles and by their number. A dense sea fog will contain more than ten thousand particles in a cubic inch and each of the particles is perhaps one twenty-five thousandth of an inch in diameter. There may be as many as twenty thousand particles in a cubic inch of such fog; a cubic foot of it would contain four or five times as many particles as there are human beings in New York City.

Other fogs are composed of still smaller particles and perhaps even with more of them to the cubic inch, but in general the fogs with large particles contain fewer of them. In any case the actual amount of water is very small. A half dozen buckets of water distributed as fog can tie up any harbor in the world.

The essential question in the phenomena of rain is: Why it forms raindrops. The essence of the

fog question is: Why does it not form raindrops? Why does it remain fog? That, of course, is merely the nature of the beast, but an explanation of that nature involves the somewhat recent study of colloids.

A fog is curiously like a salad dressing. Both are what physicists call "colloids"; materials that consist of one substance distributed in tiny particles throughout another substance. Fog is made of water particles distributed through a mass of air; most salad dressing consist of oil particles distributed in vinegary water.

It is not easy to make the oil particles stay single and remain afloat, as every housewife knows. Something draws them together, they unite to form a layer of oil and the smooth, mixed dressing is no more. Any one who could do just that to fog would be aviation's greatest benefactor since the Wrights, but unfortunately fog has the opposite habit. Once formed, almost nothing can make its particles join together and get out of the way.

Salad dressings which prove most successful in remaining dressings usually contain egg or gelatine or something that will form thin layers around the drops of oil and keep them from uniting. It is conceivable that something very similar may make for the undesirable stability of fog, but the chances are that the true reason is electrical; perhaps minute electric charges on the water drops keep them apart.

Electrified water particles are like any other electrified particles; they tend to repel each other. The fog particles, charged with the same kind of electricity, either negative or positive, would repel each

other and arrange themselves at about equal distances in space.

This probable cause of fog's stability has led scientists to attempt its disintegration by changing the electric conditions. Several years ago two scientists succeeded in dissipating fog by sprinking it with electrified sand. But such a method is commercially impractical, because the fog is dissipated only in the region where the sand is sprinkled. Even with an airplane to do the sprinkling the cost of electrifying the sand is too expensive.

Electrified air also dissipates fog. Powerful radio antennas will drive off the fog in narrow areas. But although the electric charges on individual fog particles are minute, the total charge in a bank of fog seems to be so large that a relatively enormous amount of electricity is needed to modify it. The solution of the problem obviously lies in inducing the fog electricity to change itself. At present any other method of fog dissipation promises nothing worth while.

The formation of fog, as of clouds, proceeds from the cooling of air which holds a considerable amount of moisture. In the case of clouds the cooling is caused by the rise of the air. In the case of fog cooling may be brought about in two ways. They are called "radiation"; and "advection" or "convection."

The radiation cooling is responsible for the early morning fog along river valleys and over lakes—the early morning mists beloved of poets. During the night the air has cooled by the radiation of its heat into space.

Radiation is a notable and widespread phenomenon. All substances warmer than the absolute zero of temperature continually radiate a certain amount of their heat in the form of rays. Heat rays are just like light rays except that their wavelength is longer.

A blushing maiden, for example, radiates considerable heat. The skin of the face, suffused with blood, becomes warmer than ordinary and more intense heat rays are given off. There is even an instrument which records the intensity of a blush. Chairs, tables, the walls of a room, radiate heat rays. So do gases; if a cubic foot of air could be isolated so that its radiation went on without any corresponding radiation being received, that air would promptly cool itself almost to absolute zero. The atmosphere of the earth is continually radiating heat into space.

In cloudy weather the radiation from the air near the ground is largely blocked and reflected back toward the earth. On a cloudy night, therefore, the loss of heat by radiation from air next the ground is very small. But on a clear night the radiation is much greater and that is why the clear winter nights are apt to be coldest.

On a still warm night the air over a lake or river loses so much heat by upward radiation that the air may be cooled to the point where its moisture begins to condense. This produces fog of the radiation type—which, of course, is like any other fog in everything but the nature of the process that produces it. Eddies, currents and other turbulences in the moist air just over the water are technical but otherwise unimportant factors in the process.

The "advection" or "convection" process of cool-

ing is that which produces the typical fogs of the seacoast; those of Newfoundland, for example. The warm, moist air from the warm water of the Gulf Stream drifts northward until it passes over the cold water of the Labrador Current. Because of this cold water the warm air loses some of its heat. The cooled air then produces fog just as it does in the radiation process. Virtually all sea fogs arise from this process. In summer San Francisco is very foggy; the fog bank, caused by the cold Alaska current flowing south under the warmer Pacific air, drifts over the city itself. The same type of cooling causes most of the fogs which make summer adventuring in Arctic air so dangerous. The relatively warm and moist air drifts over the ice pack and condenses its moisture into thick fog. Many land fogs of winter are produced in this same way.

The essentials of fog production, then, are a slight cooling of moisture-laden air and the almost complete absence of air movement. Too much cooling produces rain or snow instead of fog; too much air motion dissipates the fog. An absolute calm will prevent the air from mixing sufficiently to cool. A gentle drift of air with some internal turbulence is the ideal condition for the formation of fog.

City fogs are a mixture of the usual fog producing conditions and certain others which are inherent in the atmosphere over cities. It seems commonly to be thought that city fogs are largely caused by smoke and in a degree this is true. Smoke particles make the fog darker and more opaque; that is why the London fogs are so dark and dense and why the New York fogs are getting worse since the use of soft coal began a few years ago. Also the

smoke particles from city chimneys serve as additional nuclei for the condensation of fog particles. But there are always enough other nuclei in the air to take care of condensing any moisture that may be cooled out of it.

Certain chemical substances, notably sulphuric acid, are discharged into city air and it is possible that these substances attract moisture from the air and produce small drops which would not otherwise condense. That, however, it is only a possibility and a most uncertain one.

The main cause of city fogs is the fact that cities perspire, just as do plants and animals.

A city is constantly discharging into the air above it a large amount of moisture. And usually the city is warmer than open country covered with vegetation. Hence the air above a city tends to become supersaturated with moisture. As the air cools, by rising, by radiation or by slow mixture with colder air, some of this excess perspiration is condensed to produce fog. Thus the site of a city is marked by a cap of haze, even in clear weather. Airplane pilots can see this cap of haze long before they see the city itself.

The ill effects of this cloud of fog over cities are just beginning to be realized. Not only does it dilute the sunlight and so diminish the intensity of the ultraviolet rays beneficial to health, but it keeps over the city a pall of smoke and gases which would otherwise escape into space. The worst of these gases is probably carbon monoxide which is odorless, tasteless and poisonous. It can be produced by almost any kind of fire, especially by those which do not always attain perfect combustion. The burning of

gasoline in automobiles, unskillfully fired coal furnaces and imperfectly adjusted gas stoves are examples. Thousands of people have been killed by this gas; hundreds of motorists are poisoned, even to death, without knowing that they were breathing the imperceptible carbon monoxide discharged from the exhausts of their machines. This gas is unquestionably the most dangerous poison which industrial civilization has let loose on mankind.

Fortunately this gas diffuses with relative rapidity, even through a blanket of city fog. Enough of it to be definitely poisonous is seldom found in city air except on streets of enormously congested motor traffic. But evidence accumulates that slow, insidious effects of breathing a little carbon monoxide each day may be responsible for a part of the indefinite ill health of which so many city dwellers complain.

Among other gases in city air are traces of hydrogen sulphide, which smells like rotten eggs, and of the sulphur gases such as sulphuric acid. Like carbon monoxide, these sulphur gases are largely the product of fires. They do more harm to property than carbon monoxide does, if less to health. It has been calculated that the sulphuric acid brought down over the city of Leeds, England, by rain and dust reaches the tremendous total of seven tons for each square mile during the year. In New York City all the rainwater is acid. Tests show that in six months the equivalent of 1,000 tons of concentrated sulphuric acid is precipitated on that city's roofs and streets. That is enough to eat up forty carloads of iron roofing; it disintegrates even building stones.

Modern cities are continually sprinkled also, with soot and the soot is breathed by the inhabitants. The

average citizen of New York City inhales with every breath more than ten million particles of soot and dust. In a year about four hundred tons of soot, ashes and dust settles on each square mile of the city. The air of Pittsburgh, Leeds and a few other cities is even worse. Most of this could be avoided if people would take the trouble to make fires burn more perfectly. And perfect combustion is even worth money, for it saves fuel.

Except for these considerations special to cities, fog is dangerous only because it interferes with sight. About all man has been able to do to conquer it is to use some other sense, usually hearing. Admittedly, these devices of fog horns and bells are makeshifts and for air navigation they are even less satisfactory than on the sea or land. The development of fog-piercing lamps promises something. Red rays, it has long been known, pierce fog more easily than those of any colors and with electrified neon gas, electrical experts are producing red light which will penetrate fog; not perfectly, but better than the ordinary bluish rays of searchlights do.

Radio waves penetrate fog easily and there is a project under way in England to lay underground cables from which radio waves will be radiated continuously. With a device to pick up these waves an airplane pilot could follow such a cable into the airport even when he could see nothing. Similar radio cables have been tried in harbors for incoming ships to follow when fog makes the usual channel marks invisible.

From one point of view, at least, fog has its practical uses. It sometimes supplies moisture to places that would otherwise go without. Parts of the Peru-

vian coast are practically rainless, yet for several months of the year plants grow luxuriantly watered by the drizzly fog peculiar to that region. The dense fogs of the Pacific Coast of the United States have been known to put out forest fires. The "dew ponds" of southern England are fed by sea fogs and so provide water when wells run dry.

Fogs are more prevalent in some parts of the world than in others, as is obvious from the circumstances of their formation. A lighthouse just north of San Francisco is fog-bound an average of 137 days a year. Nantucket, off Cape Cod, averages 65 dense fogs a year. New York City has 23. On the Newfoundland Banks, the shallow part of the ocean east of Cape Cod, fogs have been known to last without a break for three weeks. The worst of it is that the transatlantic steamer lanes cross these banks.

Electric dissipation, neon lights, radio guides—one or another of these things, or something still unthought of may some day conquer fog. But all such things are still experimental. So far as present actualities are concerned, fog has man beaten. It is the only manifestation of weather that he has never conquered.

Chapter 13

DEW AND FROST

THE chief thing to be said about dew is that it doesn't fall, early or late, on Maxwelton's or any other braes. In fact, it rises. Rather, much of it rises, and that part of it is the most interesting.

It is, indeed, the condensed breath of the earth, and if the poets had known this their poetry might have been improved in art as well as fact.

Perhaps it is just as well that they did not know it, for dew has had a long and romantic history as it is, and more might be too much. The early philosophers and physicians, seeing dew on the ground in the morning, took a long chance and guessed that it came from the stars. The ancient names for dew implied this belief—such terms as star water, star tears, and so on.

Then the unbounded imaginations that created systems of philosophy out of nothing went even further and decided that dew was the condensation of celestial breath—the breath of stars, goddesses, or anything that might be thought to have a non-halitose suspiration. As a matter of fact, the philosophers were not far from the point after all, for dew is the breath of terrestrial things if not of celestial ones.

Dew was a potent medicine in ancient times. The fine ladies of Greece and Rome collected dew in which to wash their faces, believing that the breath

of the goddesses held marvellous power of rejuvenating beauty. The phrase "dewy complexion" still surviving in English is probably not based on the imagined resemblance between a fine skin and a fine morning. Rather, is it a fossil of speech dating from the time when women washed their faces more than they do now and so had finer complexions, no matter how dew figured in the process. The additional fact that washing in dew is apt to mean rising early may have had weight in establishing it as a cosmetic; for women who rise early are pretty sure to get to bed early and that habit, startling though it may seem, will do more for the complexion than the most expensive facial junk yet compounded. If dew were sold in fancy "flacons" at ten dollars an ounce, and if "beautors" insisted that it be applied together with ritual exercises at five o'clock in the morning, women would have better complexions. At least they would have cleaner faces.

The use of dew as a cosmetic is connected with the art—or graft—of the modern cosmetician in still another way. Grecian women and doubtless those of other countries used to spread the fleeces of sheep in the open at night. In the morning the collected dew was wrung out of the fleece and applied to the face. Such fleeces contained the natural oil and grease of the wool, the wool fat now called lanolin. And lanolin is to-day one of the main ingredients of many cosmetics, though just what good it does the face not even a sheep can tell.

Later in history men got more excited about dew. The ancient mystics who called themselves Rosicrucians did not always mean by that word Red Cross, as is supposed. They urged at times that their name

was derived from the Latin word "ros," meaning dew.

All such ideas about dew were based on the belief that it falls from the heaven. It would have been easy even for a Roman lady to prove to herself that it does nothing of the sort. The sweating pitcher of wine and snow with which she regaled her lord would have told her the story, had she not listened to the philosophers.

Like any other form of precipitation, dew is caused by the cooling of air containing a reasonable amount of moisture. The sweat on the pitcher—a pitcher of ice water will do for modern purposes of illustration—is the condensed moisture from the air that comes into contact with the cold outer surface of the pitcher. The steaming or frosting of windows in cold weather is the same thing. Breathing on a mirror will furnish an identical example.

The dew of Nature is produced whenever warm moist air from any source comes in contact with colder things. During the night the twigs of trees, leaves of grass, the tissue of a spider web and other things may cool off. Toward morning, warm air may drift across these cool objects. Moisture from this warm air condenses on twig and blade and web, and sparkles in the morning sun as dew.

Dew, then, is not unlike the accumulation of ice that is called sleet. The difference is that sleet is rain that has been chilled below the freezing point. Dew comes from moist air chilled not so much.

This theory as to the formation of dew is relatively recent in science. It was formulated after one of the best pieces of amateur scientific detective work ever undertaken. Until about a century

ago the belief persisted that dew fell from the sky. Then came Dr. William Charles Wells, an English physician with the true physician's skepticism of philosophy. In his own garden he not only watched the formation of dew but made experiments to check his theory and establish it beyond dispute.

He weighed small bundles of twigs, left them in the garden over-night, then weighed them again. Some of the bundles he protected so that they could not receive any water falling from the sky; other bundles he shielded from drifting air but left exposed to falls from above. The morning differences in the weights of his twig bundles proved his case so indisputably, when he published his famous essay on dew in 1814, that it was immediately accepted by scientific men and has never since been questioned.

What Wells had in mind, of course, was that dew condenses out of the atmosphere. The idea that some of the dew is breath of the ground is newer; Wells may have had it in mind but it was certainly not the gist of his theory.

Dew even looks as though it came out of the ground. Most of the dewdrops on leaves and blades of grass, especially leaves close to the ground, are on the under sides; that is, the side of the leaf or grass closest the soil.

The soil is not a solid layer of sand or rock or earth. Instead, it is a very loose mass like a pile of pebbles. About one half of the volume of soil is open space, sometimes as much as sixty or seventy per cent. It is much like a fine sponge whose holes take up half the space.

Within these open spaces of the soil there live many kinds of bacteria and other microscopic crea-

tures. The little rootlets of plants penetrate into these same spaces to get their food and drink. The soil is a world in itself, with its own atmosphere, its own ocean—the water films on the grains of soil—its own inhabitants, and its own vegetation.

While the atmosphere of the soil is its own, it is nevertheless in constant contact with the atmosphere of the world above. When the pressure of the air above increases some of that air is forced down into the soil; when the pressure of the upper air decreases, soil air escapes upward. Again, when the soil soaks up water from rains, the spaces between particles of earth are more or less filled with this water and their air is driven out. When the rain is over the water drains off and air enters the soil again.

Thus the soil breathes—inhales, exhales.

All this is related to dew because the air of the soil is always moister than the air of the general atmosphere; except, of course, during rains. This moisture is due, in turn, to the fact that the soil air is always in contact with the water in the soil. And this moist soil air is apt to warm up a good deal during the day because the soil around it is heated by the sun and retains that heat better than the open atmosphere does.

When night falls, this moist warm air from the soil tends to breathe out into the general atmosphere. As it does so it condenses and deposits dewdrops on the cool grass blades and twigs and spider webs. This kind of dew corresponds to the breathing of warm breath against a window pane or a mirror.

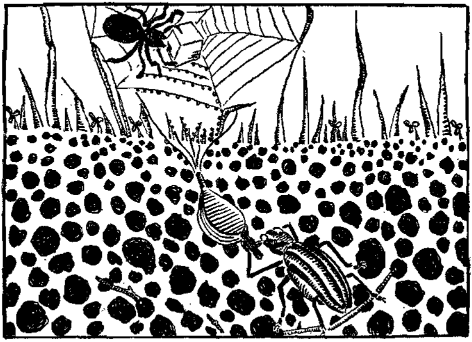
There are, then, two kinds of dew, so far as their sources is concerned. One kind, that studied by

Wells, comes from chilling of the air above ground; the other kind comes from the breathing of the soil.

The twigs and blades have to cool off enough to condense the moisture, of course. They do this by the process of radiating their heat, and that explains why dew is seldom produced on metals for metals do not radiate heat so well as vegetation and other "dewy" things. They tend rather to hold in their heat. In addition, metals have a higher capacity for containing heat, whereas most other things contain less heat in proportion to their volume. The latter, therefore, cool off to a lower temperature when their heat radiates away from them.

Some mornings are more apt to be dewy than others. It is only during a relatively clear night that radiation from objects on the earth's surface can be great enough to cool them sufficiently. And, as is the case with fogs, there must have been just the right amount of movement in the air; not too great, lest the vegetation be heated by contact with too much warm moving air; and not too slight, for then too little warm air will have passed over the twigs to leave moisture on them. When fog is formed the whole air is chilled and the moisture condenses inside the mass of air itself. When dew is formed the moisture is chilled by the thing on which it condenses.

So dew doesn't fall but rises. Poets and philosophers and beauty-seeking ladies might have been even more firmly convinced of the supernatural efficacy of dew if they had known that fact about it. They seem to have suspected at least one thing about dew that is true. It is the purest form of water that exists in Nature. It is even purer than rain water. Both are distilled water, of course, but the rain picks



DEW IS THE NIGHT-TIME BREATHING OF THE EARTH.

Moist air from the spaces between the grains of the soil rises during the night out of the soil's pores. If a spider web or a twig that happens to hang above is cold enough, dew drops condense on it, as mist gathers on a mirror when you breathe on it. It is only on relatively clear nights, when objects on the earth's surface can cool off sufficiently to condense moisture, that appreciable amounts of dew are formed: And so dew does not fall; it rises. Crystals of frost are nothing but frozen dew. Moisture from the air or the ground is deposited on something cold enough to condense it, and becomes dew. When that something is cold enough to freeze the condensed moisture it becomes frost—otherwise it remains dew. ¶ Any night cold enough to deposit frost crystals on trees and sidewalks is probably cold enough to freeze vegetation, but vegetation may freeze when there is no visible frost, for the air may be cold but not moist enough to form frost crystals. The rime on the outside of a long, cold drink is also frost.

up more or less dust and also certain soluble chemicals like salt and nitric acid as it falls through the air. Dew has no opportunity to pick up such impurities.

Hence it really is extra good for the face—if used with a little soap early in the morning.

Belonging to the same family as dew is frost. Just as snow forms a blanket to keep warm the earth underneath, so clouds and fog make blankets for the air. While they are in place, the air retains much of its warmth. But when Nature kicks the blankets off, her creatures freeze.

Frost, as a word, has two distinct, although related meanings. In one sense it is the deposit of snow-like crystals of ice on plants, window panes, and other surfaces. In the other sense, as used by farmers, frost means the night freezes which do so much harm to crops. Implied in both uses of the word is the same fact: that the temperature of the air has fallen beyond the freezing point of water.

Crystals of frost—the frosting of the first sense of the word—are really frozen dew. Moisture from the air or the ground is deposited on something cold enough to condense it, exactly as dew is formed. When that something is cold enough to freeze the moisture as it is condensed, it becomes frost. Otherwise it remains liquid dew. Any night cold enough to deposit frost crystals on tree trunks and sidewalks is almost certainly cold enough to freeze vegetation, but vegetation may freeze when there is no visible frost, for the air may be cold enough to damage plants and yet not moist enough to form frost crystals.

Frost can be formed in the same several ways as

dew. The long, cold drink in a tall glass on a hot day perspires and the outside of the glass is dewed. But if the drink is cold enough, the glass is frosted. That is why connoisseurs of the true Southern mint julep used to insist that it be served in a silver tumbler and that it be chilled until the outside of the tumbler was delicately coated with a luscious rime. Ice-cream cans containing a mixture of salt and water show the same tracing of frost. So do exposed pipes of a refrigerating machine.

When the weather outside is cold enough frost forms on the inside surfaces of window panes in the same way. "Frost pictures" are no longer common. With the advent of modern heating methods the insides of the rooms are kept sufficiently above freezing temperature so that only dew and not frost can form on the windows even in very cold weather.

Mr. Wilson A. Bentley, the enthusiastic authority on snowflakes, has also made an impressive collection of frost-pattern photographs. Like snow crystals, frost seems capable of producing the most amazing assortment of designs; fern-like, lacy tracings; stars and crosses and ladders in white-spangled symmetry that never repeats itself. Not only on glass panes and blackboards does Mr. Bentley collect his frost patterns but where the water freezes at the edges of springs and brooks. The magazines feature his pictures year after year.

The formation of these frosts follows much the same processes which make snow crystals. But the frost crystals are apt to be disturbed by minute traces of dirt on the window pane or by interference with other crystals growing at the same time so that the

frosting is less likely to be regular in shape than are the designs of snowflakes.

Even country boys of to-day may not know the secret of producing one's own designs in frost on a window pane. Any pattern may be drawn with the finger tip on a perfectly clear pane in the evening and by morning all the pane will be covered with frost except where the finger has been. The finger tip leaves a trace of grease and frost does not form, or forms less deeply, on the slightly-greased portions.

Frost can be produced by the moisture of the breath, as can dew. No window pane is needed; people sleeping in intense cold wake to find the blankets close to their faces covered with half an inch or so of crystals. Travelers wrapped in fur to the eyes sometimes have to cut away the hair about their mouths and nostrils before they can shed their coats. The whiskers of old-fashioned gentlemen who went outdoors in cold weather used to sparkle with frost as though they had woven rhinestones in their beards. Their breath blew little showers of crystals when they passed the time of day.

It is conceivable that frost can be caused by an intensely cold wind but actually almost all frost is caused by radiation of heat out of the air at night, just as is the case with dew or with the radiation type of fog. That is why frost on the ground so commonly follows a clear night and why weather-wise persons call such clear, cold nights "frosty." Since clouds or fog, the blankets of the sky, tend to hold back the heat so that objects do not get cold enough, clear nights, when the blankets have been kicked off, permit the heat to radiate better so that objects chill until they are cold enough to collect frost.

Radiation bears a relation, too, to the farmer's kind of frost. Vegetation can be killed by cold winds but as a matter of fact that seldom happens. In Florida, California, the Riviera and other fruit-growing countries where morning frosts are feared, the danger is that there will be too much night radiation from the twigs and fruits. When this happens in the spring growing crops are nipped or fruit is frozen just as it is about to "set"; that is, to take form at the end of the dying flower. In the frosts of autumn fruit is sometimes frozen before it can be harvested.

The common method of combating such frosts is based on an idea borrowed from Nature. It is, in effect, the creation of an artificial blanket to take the place of the clouds or fog with which Nature keeps in the warmth of the air.

Numbers of tin pots filled with crude oil or something else that will burn slowly are set out in the orchard when frost is expected. The slow-burning fuel makes a dense smoke. That smoke takes the place of the clouds or fog.

Smoke was considered as no more than a necessary evil when this anti-frost device was first used. Whoever invented the idea seems not to have known precisely what he was doing; through sheer luck his imperfect idea included, as an incidental, the one worthwhile feature of the whole process. What everybody then thought was worth while about these heaters was the heat—they were regarded as mere stoves to warm the air. It just happened that smoky fuel was used early in smoke-pot history.

Indeed, when these "heaters" had just come into use in California, some local genius invented a variety

of heater that gave off no smoke. He pointed that it was more agreeable to use; which was true, for there is nothing that smells quite so foul as an orchard crowded with smoke pots all under full steam. Other inventors got up electric heaters for the orchards, and one company actually tried to get orchardists to wire their trees. Alert to try anything, a few Californians gave the smokeless heaters a chance the next time a frost threatened and stood around with the inventors awaiting the result.

It was quite a surprise. The heaters heated and did not smoke, as advertised, but the flowering trees frosted as though the inventors had never given them a thought. Both inventors and orchardists were dismayed, to put it mildly; and when they got over their dismay they were puzzled, for it could be demonstrated that the new-fangled apparatus gave off considerably more heat than any smoke-pot.

Not until a meteorologist took over the investigation was it discovered that smoke, and not heat, repelled the frost. The smoke created the same kind of blanket that a cloudy night provides. Thus, by preventing the radiation of heat, it kept the trees from chilling to the fatal point below freezing.

Ever since, as might be expected, smoke pots are in high favor in California. They are also used in Florida but in many other farming countries economic reasons make them impracticable. Crops other than the valuable fruits and out-of-season vegetables of California and Florida are not worth the cost of setting out smoke pots during a dozen or more dangerous nights; at least so the growers think. In time, however, the use of smoke pots or some other device for making an artificial anti-frost blanket is sure to

be common to all farming areas where frost does much damage.

If the fog that settles over harbors and aviation fields could somehow be lent to the farmers who need it, every one would be pleased. Except as a figure of speech such a thing is absurd but the truth may lie not far beyond. If a method of dissipating fog is ever perfected it may be based on the electric relations of the fog particles. Perhaps it would be found that a reversal of this process can create fog, to counteract the conditions of temperature and wind movement that produce frosts.

The weather forecasting services in California and Florida have become quite efficient in predicting frosts and orchardists have learned what local conditions are likely to create them. The thermometer and the sky tell the story. Cold, clear nights are dangerous. Cloudy nights are comparatively safe.

Frost alarms have also been devised. An electric thermometer is set up in the orchard and connected with a bell in the orchardist's house. When the temperature of the trees drops toward the danger point the bell rings and the orchardist can get busy with his smoke pots. The thermometer, it should be realized, must warn of the temperature of twigs and fruit rather than of the air. The air can be even colder than the freezing point without injuring vegetation seriously provided that the sky is so overcast that little heat can be radiated.

It is a peculiarity of dangerous frosts that they are so frequently limited in area. In every fruit-growing region there are "frost belts" and "no-frost belts," the locations of which depend on the lay of the land, on nearby bodies of water and on

other conditions. Even in single orchards there may be spots more likely to suffer frost than other spots a few hundred feet away. Such frost or no-frost areas are fixed primarily by air drainage.

When there is little wind the air is apt to drift slowly along the ground. It may drift down a valley or off the sides of a hill. If the lie of the land and the conditions of ground heat are right, air may even drift up a hillside. Such air drainage tends to bring frost in two ways. Drainage of cold air over part of an orchard is apt to make frost there. Secondly, the air is apt to blow away protective clouds or fog. Conversely, conditions that make for the arrival of warm air or that do not hinder cloud formation will tend to protect an area from frost.

Frost is one of the two agencies that change the face of the world; water is the other. When water gets into little cracks in solid rock and freezes the rock splits because of the tremendous expansive force of the ice. Thus is it that frost disintegrates whole mountains, for rains and streams to carry away. The jagged rocks which cover the tops of bare mountains have been broken by frost. These fragments are ground finer and finer by frost and water until they become soil. The soil nourishes plants and plants nourish animal life. It is frost, then, that starts the mill of the world.

Not only does frost produce soil, it helps to keep it in shape for cultivation. Soil tends to pack down and harden; frost, with the help of the earthworm, expands the soil, stirs and loosens it. Plowing accomplishes the same thing, but it is frost that does much of Nature's plowing and that did it before either men or plows were invented.

Chapter 14

RAINBOW SURPRISES

RAINBOWS are so common that they have broken into the tenuous vocabularies of popular-song writers, yet not one person in fifty can tell what a rainbow is like!

Every one knows that it is an arch across the sky. Every one knows that it is colored. But most people, when asked what are the colors of the rainbow, will either acknowledge that they don't know, will repeat all the colors they can think of, or will mention those of the spectrum: violet, blue, green, yellow, orange and red.

Those who get so far as naming the spectrum usually add a seventh hue, indigo. But there is no indigo in the spectrum; the blue was split in order to claim seven tints for the spectrum, seven being the favorite "perfect" number of mystics and philosophers as well as of alley cubists. And just what the spectrum has to do with the rainbow is not made very clear by those who explain that, at any rate, a rainbow is something like that and that all rainbows are alike.

Which is a striking commentary on human powers of observation. Probably every human being sees at least two score rainbows in his lifetime without ever realizing that all rainbows are different. The order of the colors often differs from those of the spectrum or some of the colors are missing. There are

thousands of kinds of rainbows differing from each other in the number, tints and arrangements of the colors. Rainbows make a grand topic about which to question the offensively erudite.

In the myths and folklore of practically every people, rainbows figure extensively, as might be expected of such spectacular and inexplicable phenomena. Usually the rainbow is called a bridge; the Teutonic legend that it is the bridge of the gods leading to Valhalla is typical of thousands of attempts to explain it.

Yet nowhere is there the slightest indication that rainbows differ; a remarkable fact, for primitive men were far better observers than are civilized men. No one seems to have noticed more than one kind of rainbow. Probably the fact that two rainbows never occur together has kept ancient as well as modern man from comparing them and noticing their extreme variability. To this day, the rainbow is always represented in pictures as following the order of colors of the spectrum, the blue inside and the red outside.

Some bows, it is true, are really arranged in this order. In others the same colors exist but in reverse order. In still others and probably in the greatest number some of the six spectrum colors are missing. Most frequently blue drops out. Red is almost always present. Green bows are not uncommon, nor are bows composed mostly of red and orange sometimes with a thin border of green. In some bows there are blank white spaces between two layers of color. Again, there may be dark spaces between the colors or outside the bow, as though the sky had been painted with streaks of grey or black.

The reason why there are so many different kinds

of rainbows is seldom stated in ordinary textbooks. Rainbows are said to be simple spectra, formed as though the sunlight had passed through a prism, which is a three-sided block of glass or of some other transparent material. Such a spectrum is merely the separation of white light into various rays differing in wavelength. The colors and their arrangement are always the same.

The rainbow is no such simple spectrum. Instead, it is the piling up of a large number of spectra which have been formed in various complicated ways. Each rainbow is, in fact, a lot of rainbows, thrown together.

This whole matter of white light and its various rays of color and their various length of wave sounds unwholesomely intricate, confused and dull, but as a matter of fact the story can be told quite painlessly. Which does not mean that the plot is simple but rather that science knows enough about it to explain it in short words.

Color exists solely in the eye, not in light or anywhere else in Nature. Light is composed of certain thrills of energy commonly called "ether waves." There are in Nature an enormous variety of these ether waves and the difference between them is in their wavelength. Imagine a giant yardstick laid across the sea. The measured distance between the crests of the moving ocean waves would be their wavelength. The distance between the "crests" or midpoints of ether waves is similarly their wavelength. These lengths run a tremendous gamut but only a few of the ether waves are visible.

The longest ether waves known have wavelengths of about a hundred thousand meters, which equals

fifty miles or so. These longest waves are radio waves, but the more common radio waves run from about 200 meters to about 500 meters, which means from some 600 to 1,500 feet, a meter being approximately three feet. The shortest radio waves are only a fraction of an inch in wavelength but are not yet of any practical use. All the radio waves are invisible.

Shorter than radio waves are those of heat, the thrills of energy given off by anything said to be hot; by the sun, by a fire, by a heated iron. Heat waves, too, are invisible.

Shorter still than heat waves are those of light. When ether waves shorten until they are only one thirty-thousandth of an inch in wavelength they become visible; that is, the impact of these minute thrills of energy against the eye starts a chain of happenings that results in the thing called vision. Not as individual rays are they visible, of course, but merely in their net effect. That is light. Waves a bit longer than this critical thirty-thousandth of an inch are invisible; they can be felt but not seen.

Ether waves are still these light waves until they are shorter than about one seventy-thousandth of an inch. Then their contact with the eye no longer results in an impression of light on the consciousness. Still shorter, invisible rays exist; in order of decreasing wavelength and descending scale of ether waves, they are the ultraviolet rays, the x-rays, the gamma rays of radium, and finally, as the shortest ether waves yet identified, the cosmic rays which come mysteriously from space.

That is the gamut of ether waves—from fifty miles to much less than a billionth an inch. The eye

sees only that very small division of this gamut between about one thirty-thousandth of an inch and about one seventy-thousandth of an inch. Yet all the kinds of ether waves in this great gamut are believed to be exactly the same except for wavelength; radio waves and heat waves are longer than visible light; ultraviolet rays, the "letter" rays and cosmic rays are shorter.

This fact that the eye can see only the waves within a small subdivision of the gamut is pure accident. It happened that eyes developed under certain earthly conditions. There is no reason why, under different conditions, eyes that could see heat, radio, gamma rays or any other kind of ether waves might not have developed equally well. Some very pretty speculations have been founded on what the world would look like if the eye could see waves other than those of light-wave wavelength.

This light-wave division of the ether wave gamut is subdivided into color waves and these also differ only in their wavelengths. Waves of one wavelength produce a different impression on the eye than do those of other wavelengths; otherwise their nature is the same. The longest visible rays are red. The others, in order of decreasing wavelength, are orange, yellow, green, blue, and violet. There visibility ends. The next shortest waves, those of ultraviolet, cannot be seen.

Ordinary light, like that from the sun or from some very hot thing such as the filament of a tungsten lamp, is a mixture of all these visible rays, and usually some invisible heat rays and ultraviolet rays also. This mixture, this ordinary light, is called white. In reality there is no such thing as white

light. The whole conception of it is an artificial idea. White is simply the name for the sensation caused by the entrance into the eye of many wavelengths of light mixed in more or less equal proportions. The different wavelengths present in mixed, white light do not fuse physically; the fusion that makes the sensation of white takes place solely in the eye.

The separating of these various light waves according to their wavelength makes a spectrum. The trick may be done in many ways but most conveniently with a prism. When a beam of mixed rays, such as a beam of sunlight, passes through a prism in the proper manner it emerges as a strip of separate wave lengths. The prism has split the beam and sorted it, so that the shortest waves are at one end of the strip and the longest at the other. These separated and ordered waves, thrown against a screen or something else to make them visible, form the spectrum which so many people confuse with the rainbow.

Not only prisms of glass make spectra. A great many other transparent objects accomplish the same thing. But if the transparent object is not three-sided the light waves passing through it may emerge in more complicated order of colors. Thus, when a beam of white, mixed light encounters a globe—a globe of glass or a globe of water like a raindrop—part of the light is reflected from the surface of the globe. Another part is reflected inside the globe; that is, some of the light strikes against the interior walls of the globe and bounds around inside it from one part of the wall to another.

Some of this internally reflected light emerges in the direction from which it came, as though it had

been reflected from a mirror. Some of it emerges in the forward direction and goes on much as though it had never encountered the globe.

The things that can happen to light rays inside a transparent globe such as a raindrop would scarcely bear counting. So complicated are the possibilities that they are not by any means fully understood. But one thing that can happen is the separation of the colors. This means that the different wavelengths of light can be split apart so that they leave the globe in different directions but in much more complicated fashion than they leave a simple prism.

That is the why of a rainbow.

Rainbows are formed only when rays of mixed or white light—the visible wavelengths of ether waves—pass through water drops such as the drops of a shower. For a rainbow to form during or after a rain it is necessary to have a "sunshower"; that is, a sheet of falling rain on which the sun is shining from the edge of the rain cloud. For this reason rainbows are more apt to occur in morning or evening. The sun is so high at noon that its rays cannot get underneath the edge of the rain cloud to strike the sheet of rain. For the same reason rainbows are commoner in summer than in winter; summer showers are more apt to be local so that it is raining in a restricted area with clear sky close enough to permit the sun's rays to strike the curtain of rain. Winter rains are usually so widespread that the sun cannot get into the picture.

Nor is the sun essential to the formation of rainbows. Light from any other source will do provided that it is mixed, white light. Moon rainbows are not uncommon. Strong electric lights shining through mists or fogs form rainbows. Neither need the

globes of water be raindrops. Sunlight will form rainbows when it strikes the spray at the bottoms of waterfalls or spray from fire-hose or the steam from locomotives. All that a rainbow needs is a strong light shining on or through a mass of water drops.

There are many kinds of rainbows for two reasons; the complicated things that can happen to light waves while they are being reflected around inside a raindrop, and the varying sizes of the raindrops; for this size is an important factor in determining exactly what happens when light waves are split up into the different colors. So multitudinous are the number of things that can happen that it is quite possible that no two natural rainbows have ever been alike.

The fact that some rainbows lack their full complement of colors may be explained by the assumption that the missing wavelengths got mixed up somewhere inside the raindrops and never got out. But more likely the explanation is that one color is superimposed on another so that they cancel each other in the eye. One of the few things firmly known about the theory of color vision is that colors are perceived in pairs and that they often cancel each other in pairs; a fact at the bottom of most of the talk about color wheels and charts and schemes to which artists and interior decorators are given. It is fortunately unnecessary to pursue those theories of color here further than to say that red and green, for example, cancel each other and appear as dull white, yellow white, or grey, depending on the purity of the original red and green.

Color cancellation may easily happen in the forma-

tion of rainbows. The bows are often double, sometimes treble; one formed by light once reflected inside the raindrops, the second by light three times reflected and so on. These several sets of colored beams, enough for several distinct rainbows, may emerge at such angles that they overlap as they enter the eye. It is as though the colors had been painted one over the other. Thus some of the colors may cancel each other, others may merely alter or reinforce their companions. The result is the variety of colors, missing colors, dark bands of the bow, and so on, as these are actually seen.

Since emerging rays may be reflected either toward the sun or away from it, the observer facing the rain may find the sun behind him or behind the rain. But usually the sun is behind the observer and the rain in front of him.

No two persons have ever seen the same rainbow. There must be a different set of light paths and rays for each position of the eye that sees them. The eyes of persons standing shoulder to shoulder perceive entirely different sets of rays moving along different paths. That is why the end of the rainbow can never be reached. Whenever the observer moves the rainbow moves too. There is never only one rainbow in the sky, but millions and indeed billions of them. A rainbow shower really fills all nearby space with a vast network of colored light rays, as though billions of tiny, colored searchlights were shining. If these rays could be seen as they lace and interlace through the air—as beams of searchlights can be seen by the dust motes which they illuminate—the air during a sunshower would be a flashing mass of every conceivable color, sparkling, glittering on and off and

playing in every direction. It would be like living inside a diamond.

It takes billions of raindrops to form a rainbow and the work of each drop lasts only a fraction of a second, for while the bow hangs in the sky the drops themselves are falling. Each drop flashes its colors for a tiny instant. As it drops out of the area in which the sun's rays strike it another drop follows to take its place in the rainbow-forming zone, one example of collective action in nature.

This is the reason, too, why the rainbow is arched. It is not any individual set of raindrops that produce the bow, but merely the drops which occupy, one at a time, the places in the sky which make the same angles of sight with the eye of the observer and with the sun. These critical places, the seats which drops must occupy to make the bow, are ranged in a partial semi-circle, like the rows of seats in a theatre.

"The sun drawing water" is another phenomenon of the rainbow-sunshower group. Its appearance is of visible light rays stretching from the sun to the land or sea, like searchlight beams shining from above. The explanation is much the same as that of the searchlight; the sun is shining through holes in the clouds and its beams are made visible by dust motes or water particles in the air. A smaller beam of sunlight is made visible in the same way when it shines into a dark room through a chink in the shutter. As to the sun drawing up any water in this process, that is either folklore or poppycock, depending on one's appetite for the fruits of the imagination.

Halos, "sun dogs" and other like phenomena with somewhat fancy names are reflections of sunlight or

moonlight from myriads of very tiny ice crystals floating high in the air, like clouds. Usually these reflections are colored. Less often they are merely the color of the original light, since the reflection has not been of the type that separates the light into its different wavelengths. But the reflection is not precisely the simple reflection of a mirror, for certain other processes with impressive names like diffraction and scattering have something to do with it.

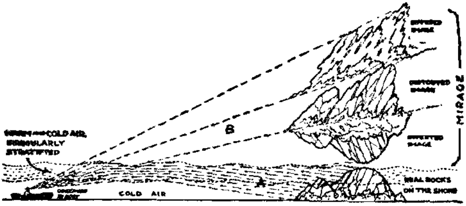
Some of these halo phenomena are very impressive, indeed frightening to people who go in for being frightened by that sort of thing. Three hundred years ago a set of halos scared the peasants of Rome out of what wits they possessed; so badly, in fact, that their descendants still remember the event and meteorologists have given it the name of the "Roman phenomenon." Four "mock suns" were seen surrounding the real sun, and one of them exuded fiery beams. The cause was simpler, if possible, than the peasants. The mock suns were merely the points at which systems of bright halos intersected, the halos being caused by the reflection or diffraction of the sunlight from dust, ice crystals, or something else high in the air.

Anything extraordinary that happens to light rays naturally plays some sort of trick upon the vision of the beholder. Sometimes he sees things that aren't—a mirage, for example. In print, almost all mirages are seen either by desert travellers fainting with thirst or by mariners yearning for land. The result is that so much of the exotic attaches to the word that ordinary buck privates of the home-guard refuse to be taken in. Their skepticism is unwarranted, for there are such things as mirages and even people so

unobservant as automobilists see them time after time, whether they know it or not. On hot, still summer days puddles of water sometimes seem to lie on asphalt roads when really the road is quite dry. These mirage-puddles are caused by accumulation of hot air next to the surface of the road. This hot air bends upward the light rays from the sky ahead as though from a mirror, giving the appearance of water. What the automobilist really sees as he approaches such a mirage is the sky reflected in the road.

Desert mirages are the same thing. The air next the ground gets overheated and reflects the distant sky. If mountains or trees happen to be silhouetted against that sky they too are reflected and somewhat distorted by the bending of the layers of air that make the mirror, so that all sorts of images result. Ships, houses, parades, statues, the Washington Monument, elephants, all sorts of things seem to hang in the air above the desert or to lie on its surface. And, of course, the mirage frequently looks like a placid pool of water. But there is an indefinable something about it that undeceives the old "desert rat." He knows it infallibly for the mirage that it is.

The books are full of mirages at sea but there is little exact information about them. Presumably there could be a sea-mirage caused by the bending downward, instead of upward, of the light rays. It should be observed, however, that the most striking of these tales of distant cities seen by mirage date back to times so early that all possible witnesses are dead. Like anecdotes of sea serpents and mermaids, the stories are always second-hand; somebody once



BUILDING THE ENCHANTED PALACE OF MORGAN LE FAY.

In the strait between Italy and Sicily images of real rocks are made by light rays bent in layers of cold and warm air. These form the famous mirage of the Fata Morgana. Two or three images of the same rocks may be piled on top of each other, to look like towers or castles or the buildings of a city. Mirages are really much commoner than people imagine. The puddles of water that seem to lie on asphalt roads that actually are quite dry, on hot, still summer days, are mirages caused by the accumulation of hot air next to the surface of the road. This hot air bends upward the light rays from the sky ahead. What appears to be a puddle of water is really the sky reflected in the road. Most famous of all mirages are those of the desert, which are also caused by overheated air close to the ground. Mountains or trees that happen to be silhouetted against the sky are reflected and their images distorted by the bending of the layers of air, so that the mirage may have the appearance of ships, houses, parades, and, of course, the classic pool of water toward which the panting sufferer drags himself, to die of thirst and disappointment. There are also mirages at sea, but the exciting stories about them are usually exaggerated. They are caused by rays of light bending downward instead of upward.

knew a man who knew some one else who, and etc. A little skepticism does not hurt in listening to these tales of cities seen thousands of miles away via mirage.

One sea mirage is real enough although it is not quite so startling. In the Strait of Messina, between Italy and Sicily, a fisherman may see, two or three times in a lifetime, the towers and battlements and palaces of an ancient city rise through the morning mists. This is the Fata Morgana, the castle home of Morgan le Fay, wicked enchantress and sister of the legendary King Arthur of the Round Table. She is showing the vision of her home, tradition says, to those whom she would lure to death, for her real home is under the waves. Fishermen all over the world have similar legends but nowhere else is the mirage so clear as in the Strait of Messina. Its cause is the same as that of any other mirage, the bending of light rays by the air and the distorted reflection of distant hills.

Chapter 15

THE WEIGHT OF AIR

THE barometer looms too large in most discussions of weather, whether of country store or classroom variety. Either because it was the first instrument invented to predict the weather or because its use has largely to do with cyclones and sea captains and other such impressive and romantic entities, the device which indicates the pressure of the atmosphere has taken on an importance it does not deserve, so much so that it is lovingly termed the "weather glass," as though it alone could predict the changes of weather that a dozen other instruments in the hands of experts fail to forecast with any overwhelming accuracy.

Descriptions of barometers and advice as to their use make dull reading for any but meteorologists but the thing with which they deal, air pressure, is not only an important but to most people an interesting matter.

The facts of air pressure resolve into a statement startling enough to make a tabloid newspaper headline: Thousands of pounds rest on every human being but do not crush him. Most of the facts were known, however, before the tabloids leaped upon the scene.

In the ancient German city of Magdeburg, many years ago, a famous experiment was performed. A man of science made a large, hollow copper sphere,

cut in two like the halves of an orange. Then he hitched a team of horses to each half of the reunited sphere.

There were no bolts to fasten the halves together but a small pipe led to their interior. At the other end of the pipe was a pumplike apparatus. The man of science did something to the apparatus, then bade the horses pull. The horses strained, but they could not pull the hemispheres apart.

Not until the man did something else to the apparatus could the horses separate the sphere. There was no magic about it; the man of science had merely utilized the enormous force of the pressure of the air.

Man lives at the bottom of an ocean of air, as crabs live on the bottom of an ocean of water. The air has weight. In the aggregate it weighs millions and millions of tons. A square inch marked on a board held in the open air is the bottom of a column of air reaching to the top of the earth's atmosphere. That column weighs almost fifteen pounds. The air pressure, in general, is about fifteen pounds to the square inch.

An extended hand supports a weight of twenty-five or thirty such columns of air—some three to five hundred pounds. That is more than a man can lift, yet the most delicate woman can stretch out her hand in the air.

The explanation is, of course, that air is a fluid and that its pressure is exerted equally on all sides and up as well as down. The pressure on the upper side of the hand really is several hundred pounds, but the pressure on the under side is equal in amount and thus balances. The net weight on the hand be-

comes nothing. But if an air pump takes away the pressure from beneath the hand, the unbalanced weight will force it down into the airless hole and may even crush the bones.

That was the secret of the Magdeburg experiment. The man of science merely pumped the air out of the hemispheres so that there was no pressure in them. Then the pressure of the outside air held them together tighter than bolts would have held them.

But if the pressure on all sides of the hand amounts to several hundred pounds, why is not the hand crushed, as though in a vice? Why are not all living bodies mashed flat by air pressure?

The answer is the same as that which explains why creatures can live at the bottom depths of the sea, where the water pressure is more than ten tons to the square inch instead of fifteen pounds; a weight more than enough to crush to pulp any creature living above those depths, a pressure that would crush bones to powder. On the sea floor there live, however, fragile, crablike creatures whose bodies would break of their own weight if dropped on the floor.

These creatures can live under such pressure because the fluid making that pressure penetrates their bodies. The crabs' bodies are full of water; the pressure inside is the same as that outside, hence there is no net pressure.

So with animal bodies in the air. Pressure in the lungs and other air-filled cavities, water pressure in the heart and blood vessels, all are adjusted to meet the normal air pressure. Animals are constructed to live in fifteen pounds of air pressure to the inch; sea-bottom crabs to live in ten tons of water pressure to the inch. Bring sea-bottom creatures to the sur-

face and they explode; sink an ordinary animal to the bottom and it caves in.

But humans, at least, can adjust themselves to changes of pressure that are not too great. Higher in the air, in aircraft or on mountain tops, the pressure is decreased; the fifteen pound pressure obtains for sea level. As the air pressure decreases on the outside the air and water pressure inside bodies decreases also, if given time. A tense feeling in the ear is an occasional symptom of too-sudden change in air pressure, even such slight changes as those resulting from the movement of an elevator. But the inequality on the two sides of the eardrum is adjusted as quickly as air can get to the inner ear or from it through the Eustachian tube opening into the throat.

The fact that air pressure varies with height explains why barometers are used to measure the elevations of mountains or the height of aircraft. Corrections are necessary, however, to allow for other changes in the atmosphere, for the air pressure at sea level may vary by five or ten per cent. Barometers designed for aircraft are usually of the type called barographs, because they write a continuous record of air pressure and its changes during ascent and descent.

The uses to which barometers are properly put in weather forecasting are limited to determining just this change in air pressure. Such pressure, however, is a most important indication in ascertaining the location and probable movement of the cyclonic storms and the "isobars" or lines of equal barometric pressure are a properly prominent feature of the weather maps.

One of the most important, but still problem-

atical, direct effects of changing air pressure is that on earthquakes. In many parts of the world it has been demonstrated that changes in air pressure cause slight tiltings and tremblings of the ground. Typhoons in the China Sea, for example, are accompanied by sudden and considerable changes in air pressure and it has been found that when these storms occur feeble but perceptible earth tremors are recorded at Chinese earthquake observatories. It seems possible that changes in air pressure have something to do with more severe earth shocks also.

The air presses on the ground, of course, just as it does on everything else. Earthquakes, according to present theories, are a long time in the making; the stress in rocks which causes them accumulates slowly. Only when the stress becomes so great that the final straw breaks the back of the rocks does the shock occur. Changes in air pressure may be the final straws.

There is an ancient and widespread idea that there exists a special kind of weather favorable to earthquakes. This "earthquake weather" is described as still, sultry and humid—conditions definitely related to high air pressures. Whether bad earthquakes really are apt to occur in such weather nobody knows. The point deserves investigation.

Chapter 16

WINDS IN CURLS

THE trouble with the wind is that it curls. It curls and it spirals, it corkscrews and whirls and eddies and generally revolves in such dizzy fashion that it is no wonder St. John said: The wind bloweth where it listeth.

Nor is there anything censurable about the apostolic idea except that it is wrong. The wind bloweth, not where it listeth but where a lot of other things list that it shall blow. There are so many of these things that the best the wind can do is to circle, with no obvious intent or goal.

The catalogue of things that keep the wind spinning begins with the sun and includes the temperature and the pressure of the atmosphere, the rotation of the earth and the inertia of matter; touches on Einstein's theory of relativity here and there and ends—well, it ends with a lot of whirls and eddies of wind, and poetic phrase.

The thing that once started the winds to blowing and that has kept them blowing ever since is, as might be expected, the sun. The changes of temperature originating in solar energy would be sufficient to cause plenty of wind, even if there were nothing else to keep it going. Any mass of air that is heated tends to rise. Since there can be no void, cooler air from somewhere else must sweep in to take the place of the risen mass. That is a wind.

The place left vacant by the cool air is filled by still another mass and so *ad infinitum.*

But so many complications interpose between the sun as cause and the winds as effect, that the actual movements of the air at any given time and place bear only a remote relation to heat or sunlight.

The matter of air pressure is one such complication. It may be thought of as the most important instrument used by the sun to stir up winds. The heat of the sun makes differences in air pressure and differences in air pressure make winds.

Two people hold a rug, flat, over a dusty floor. They let the rug drop. As it falls a cloud of dust is blown out from beneath it—the air trapped under the rug is blowing out and carrying the dust with it. That is the effect of air pressure. The weight of the rug is added to the weight of the air beneath it, thus increasing the air pressure until it is greater than the pressure of the air around it, which is forced out toward the areas of lower pressure.

That is exactly what happens—or would happen if nothing in the way of complications arose—when a high pressure area is created in the atmosphere by temperature changes or anything else. Winds blow outward from high pressure areas. They blow inward toward low pressure areas.

That would be enough to explain everything about winds if the earth were a perfect sphere standing still in space and were otherwise as simple and well-behaved as mathematical theorists would like it to be. On such a scientifically-convenient earth, all winds would blow from the cold poles to the warm equator. There would be no other kind of wind, and nobody would have to think up a saying to the effect

that winds blow where they list, for they wouldn't; it would be like saying that stones fall or don't fall as they happen to choose.

But the winds do not stick to this north and south routine. Certain complicating factors disturb what would otherwise be a simple circulation of the air caused by pressure, as the weather map shows. Direction of the winds is indicated on the map by arrows. The areas of high and low pressure are not only marked by the words "high" and "low" but by the isobars, or lines of equal air pressure. If the simple air pressure circulation obtained all wind arrows would point away from the "highs" and toward the "lows." Such a condition is hardly ever seen on a weather map. Almost always the winds are shown blowing around the highs and lows like merry-go-rounds; the winds are following their tendency to curl.

The thing that makes the curl, basically, is that often-forgotten property of the universe called inertia, the thing that, according to Einstein's theory of relativity may be the most fundamental in the universe—more fundamental than either matter or space.

Inertia is what throws people through windshields when automobiles stop suddenly. It makes a revolver bullet dangerous. It keeps the earth from falling into the sun. It makes trains and ships smash up when they hit other trains and ships.

Inertia is, by definition, the tendency of everything in matter to keep on doing what it is doing, or, in technical language, "to remain at rest when it is at rest and to continue moving in a straight line and with a constant velocity when it is in motion."

There are two main ways in which inertia works upon the movements of the air. The wind itself has inertia, for one thing; the rotation of the earth supplies an effect of inertia, for the other. The inertia of the wind is manifest in its pressure in severe storms, as any one who has felt the impact of a hurricane knows. The wind could scarcely be felt if it had no inertia.

A good illustration of the effects of inertia is the movement of a flying baseball. Once started by thrower or bat, the ball has inertia. It tends to keep on going forever. If there were no air to retard it by friction and no gravity to pull it to the ground, the baseball would keep on going forever. Even in fact, because of its inertia, it holds its course largely undeflected. Wind pressure may deflect it a bit, as it deflects even artillery projectiles, but this deflection is never complete enough to turn the ball around or stop it.

By the same token, a mass of air set in motion tends to hold that motion; it keeps on doing what it is doing. A difference in pressure may deflect it from its path, but it will take time for that sidewise pressure to turn the wind aside altogether from its original motion.

The wind's own inertia tends, therefore, to keep it going in a relatively straight line. It does not keep going in a straight line because the earth rotates.

The earth has inertia and everything on it has inertia, and when two forces of inertia collide one gives way, or both. Geographers noticed long ago that rivers flowing north and south tend to cut away one bank more than the other. In the northern hemisphere rivers flowing south, like the Mississippi,

tend to veer toward their western banks, while northbound rivers such as the Nile hug their eastern banks. In the southern hemisphere the streams show a reverse tendency of current.

A similar law is applicable to the winds. The uniform winds which would blow, on a stationary and featureless earth, from the poles toward the equator, are altered by this tendency to veer east or west. The wind is moving across the earth and the earth is turning beneath it. The speed at which any spot on the earth's surface moves depends on its distance from the pole or the equator. Thus, as the wind moves along over the earth's surface it passes over spots which are moving across its path faster, if the wind is blowing south, or slower, if it is blowing north, than the spot which the wind has just left. Because its inertia tends to make it move in a straight line through space, the direct north or south path of the wind becomes a drift eastward or westward, the same drift to which rivers are inclined. But there are no shores of earth or rock to bound these wind currents and to oppose inertia with greater inertia, hence the results are more complicated than a mere wearing away of river banks.

Tremendously difficult is all this to visualize without some sort of model. Fortunately, however, Professor William Morris Davis of Harvard has devised a means of illustration. Even if the experiment is not actually carried out, its description makes the point clear.

Take a table with a round top that can be revolved, such as the condiment tables used in some restaurants. On the top lay a sheet of paper and on the paper place a marble with a drop of ink on it.

Shove the marble gently. If the marble is true, the table level and the paper smooth, the marble will roll in a straight line and leave a series of ink dots to mark its path. That represents a wind moving straight by its inertia over a stationary earth.

Then start the table to rotating slowly and give the marble another push. This time the line of ink dots will be curved, not straight. The rotation of the table made the marble draw a curved line.

Just so does the wind follow a curved path along the rotating surface of the earth. The marble does its best to stick to the straight line, and so does the wind, but the revolution of the table and the earth make their lines of flight seem crooked.

So far the discussion and Professor Davis's experiment have assumed, for convenience, that the earth's surface is flat. The fact that the wind has to follow the earth's curved surface is still another complication. Inertia would tend to drive the wind off the earth along a straight line into space, as though it followed a ruler held against a ball. But gravity prevents that disappearance into the void; the wind has weight as well as inertia and so it must come down. It comes down over a whirling, rounded surface and it comes down in a curlicue course.

Dismally complicated as are all these facts about the motion of the winds they are actually just the bare beginnings of the full explanation. It is very much like the story of the Englishman, the Frenchman, the German and the American, each of whom was commissioned to write a book about elephants. After a few weeks the American turned in a manuscript entitled: "Coining Elephants, or Let the Big Boys Make You Rich." Some time afterward the

Englishman submitted "My Life, With a Record of Kills and Tusk-weights." Still later the Frenchman presented "Les Coquettes de la Forêt; Vie et Amours." Nothing was heard from the German for three years. Then he came across with his work: "Notes, In Three Volumes, On a Projected Introduction to the Study of the Probable Evolution of the Elephant's Eyelashes."

The German might have spent that much time getting ready to discuss winds, for a full explanation of their motions would fill a mathematical treatise of a thousand pages. Unfortunately, such treatises have been written.

The man who first understood these sickeningly complicated facts about the effects of the earth's rotation on the winds was, however, an amateur of science. Some of the causes had been vaguely hinted at before his time, but the man who put the essentials in such shape that the theory could be used in meteorological science was W. Ferrel, a school teacher in Nashville, Tennessee. Aroused by published statements which he knew could not be true, Ferrel worked out the theory in 1856, before Tennessee had soured on scientific knowledge, and published the rules for wind motions on a rotating earth in the Mathematical Monthly of Cambridge, Massachusetts, in 1860. Ever since then his theory has been the basis of what science knows about winds. His work is one more instance of an amateur doing a piece of scientific work better than any one had done it before.

With so many factors at work, it might seem that the results would almost nullify each other—that almost there would be no winds other than short,

sharp gusts meeting each other head on. But with a sort of fatality, all the disturbances set up by inertia, by the rotation of the earth, by friction with the ground and with other winds—all these disturbances produce one general effect. Ferrel and his successors have proved by rigid mathematics and observers have confirmed this result: The winds are set to whirling. That is the net result of all forces that work on winds. Winds are whirls. An observer far in space, if winds were visible, would see the earth covered with a maze of continually whirling wind eddies. Some would be almost as big as the earth, others as small as the curls that scoop papers off a city street or the dust-devils of the deserts.

This tendency to set winds whirling is unquestionably the reason for the cyclonic storms that have so much to do with weather in the United States and for the circling of the wind arrows around the "highs" and "lows" of the weather map. It accounts, too, not only for the hurricanes and typhoons and other circular storms but for the greatest spirals, the constant winds of the earth called the trade winds.

This name, incidentally, has nothing to do with commerce. The trades got their name from the older English meaning of the word, a straight path, with the same connotation as the word tread. The winds are named because they follow the same path for months at a time.

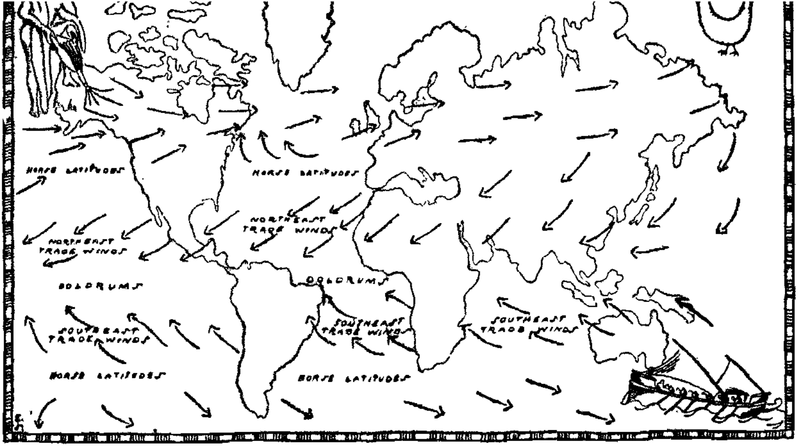
There are trade winds in the middle latitudes of both hemispheres, blowing to the southwest in the northern and to the northeast in the southern hemisphere. The strongest and most constant trade winds are those of the North Atlantic and South Atlantic. Bordering the trade wind zones are the "horse lati-

tudes," so called by masters of sailing ships. Here there are wide belts of calms, dreaded by all mariners before the days of steam. The "doldrums," another belt of calms, lies between the trades of the North Atlantic and those of the South Atlantic.

Such belts of constant winds and relatively constant calms were of extreme importance when all the world's commerce was carried by sail. They dictated the general movement of discovery and settlement, and though to-day they matter little, the most used traffic arteries of the world still run east and west rather than north and south. Only with the perfection of air travel will north and south traffic begin, perhaps, to equal that which follows the latitudes because the trade winds follow them.

The sea and land breezes which spring up morning and evening alternately in many parts of the world are purely a phenomenon of temperature. During the day the land gets heated by the sun. Toward evening the hot air over the land begins to rise, and then a breeze cooled by the sea blows landward to take the place of the rising land air. During the night the reverse occurs. The land cools off until it is cooler than the sea. Then the sea air rises and the land air returns to take its place.

The monsoons of India, not to be confused with the little beast called the mongoose, are nothing more than these same alternating winds on a bigger scale. The name derives from an Arabic word meaning season, and the monsoons are seasonal winds; a whole summer takes the place of the day and a winter that of the night in heading the winds off shore or landward. During the winter the land area of Asia is cooler than the waters of the Indian Ocean and so



WHERE THE WIND GODS FAVORED OLD-TIME MARINERS WITH BREEZES OR DELAYED THEM WITH CALMS.

The trade winds are named because they are constant in direction; not because they were used in trade.

the winter monsoon blows toward the sea. About May the situation changes and the land becomes warmer than the ocean. Then the wind shifts and blows toward the land. Since it is these sea winds that bring to India the moisture necessary for crops, the arrival of the summer monsoon is a very important date in the Indian calendar—as important as was the arrival of the spring floods for the Babylonians. Fundamentally, of course, the monsoons are moved by the great whirl of the winds over the Indian Ocean but their regular alternation is due mainly to the seasonal circulation.

Less constant monsoon winds blow over other parts of the earth. In eastern Texas, for example, the winds blow mainly from the south in the summer and from the north in the winter. Thus the summer is hotter and wetter than it otherwise would be, and the winter colder and drier. But Texas is within the limits of the northern storm track along which the cyclonic whirls chase themselves and so its climate is not entirely determined by the monsoon tendency of its winds.

All of which shows that the wind bloweth not where it listeth, but rather where the sun and the whirling earth list, no matter what poets or apostles may think about it.

Chapter 17

CYCLONIC POWERHOUSES

THE vast whirling winds called cyclones and tornadoes are among the most violent and powerful of all natural forces. A cyclone may expend enough power in one day to run all the dynamos, motors and steam engines in the world for three or four years. A tornado in five minutes has been known to kill 250 people and to destroy $15,000,000 worth of property. The energy set loose by one wide-spread storm may be greater than that of an earthquake or a volcanic explosion.

Where does all this energy come from? What starts a cyclone?

For a long time scientists were at a loss to understand even the beginnings of this problem. Now they are reasonably able to explain.

First, it is necessary to avoid a common confusion of names. There are two distinct types of these violent storms and the word "cyclone" has been applied, popularly, to both. More precisely, they are the hurricane and the tornado.

The name of hurricane is given to the first of these types when it blows in the Gulf of Mexico or the Caribbean Sea. Around the China Sea the same kind of storm is called a typhoon. In other parts of the world it has other names but the meteorologist lumps all these local names in one and calls this type of storm a cyclone.

From Colorado to Ohio this word cyclone is a common one. There is talk of "cyclones" hitting such and such a place, of people fleeing for safety to "cyclone cellars," and so on. But the type of storm meant by all this is not the meteorologist's cyclone at all. It is a tornado.

Both cyclone and tornado are whirling storms. They are, in fact, manifestations of the tendency of the wind to blow in whirls. But they differ from each other in their origins, in the ways in which their energy is set free and in the size and shape of their whirls.

The typical cyclone is the West Indian hurricane, the type of storm which occasionally does so much damage in Florida. It is a large flat whirl usually hundreds of miles in diameter. At its center is a calm spot around which the whirling rim of air revolves. A good model is a big, flat doughnut or cruller. If such a cooky could be spun around and slowly pushed over a map it would be a working model of a hurricane or cyclone.

The tornado, so frequently miscalled cyclone, is a much narrower storm and in proportion, much taller. The whirling funnel of dark cloud that constitutes a tornado may be only a score of feet in diameter. It seldom measures more than a few hundred feet. It is the most violent of all storms and moves more rapidly, but since it is of relatively small size it does not release anything like the energy of the larger but less violent cyclone.

Waterspouts are merely tornadoes at sea. The suction in the center of the tornado, created by centrifugal force, lifts up a column of water.

The air whirl that constitutes a hurricane is much

broader than it is thick. It may spread a thousand miles across the sea but it seldom extends upward more than eight or ten miles, and usually is not that high. The hole at the center of the hurricane doughnut is the oft-mentioned "eye of the storm," the calm that comes between two winds as the hurricane passes. In the Miami hurricane of 1926 this eye passed almost exactly over the city and was noticed by every one as a calm between two violent winds. Passing beyond Florida, this storm continued its westerly drift, whirling violently the while, until it crossed the coast of the mainland at Mobile and vanished as the whirl slowed down.

Such observation of hurricanes as meteorology possesses is owed to ship captains or weather observers who happen to get tangled up with one and spend most of their energy, no doubt, in wishing they were elsewhere. The inside of a hurricane whirling at a hundred or a hundred and fifty miles an hour is not the ideal place, from one point of view, for making accurate scientific observations. Probably that is why science has so long been puzzled by two mysteries of these great air whirls, the source of their energy, and the place of their origin. No one has ever seen a hurricane start; by the time one reaches the West Indies from the open sea it is in full career.

The most recent theories of the hurricane's power have been published by Dr. Isaac M. Cline in his book "Tropical Cyclones." Dr. Cline has had the not too enviable fortune to be inside ten of these storms and has collected data on six others. Using an original method of plotting the internal wind movements of these sixteen whirls, he has located, he believes, the source of the cyclonic energy.

Scientists have always ascribed this energy to the condensation of rainwater inside the hurricane. Such condensation is known to yield a great deal of power. The difficulty with this theory, however, was in discovering where the storm obtained the vast quantities of water vapor necessary for this condensation. The necessary water carrier, as Dr. Cline believes, is in the form of a wind which blows continually toward the hurricane from behind.

In the northern hemisphere the rotation of the earth sees to it that the spin of a cyclonic whirl is counter clockwise. The older idea was that this rotation was more or less uniform in all sectors of the whirl, as it necessarily would be in a spinning solid body like a doughnut.

This, Dr. Cline finds, is untrue. The most violent winds occur in the front right hand quadrant of the storm, he discovers, "front" being taken as the direction of advance. Behind this, in the rear right hand quadrant he finds a violent wind, not blowing in strict circular relation to the whirl but following the advance of the storm and blowing in much the same direction as the advance. It is this upcoming wind in the rear which constitutes the water supply system of the hurricane.

Somewhere, miles in the rear of the storm, the surface water of the ocean is absorbing sunlight, growing warmer, evaporating. The warm, water-charged air thus produced is sucked forward by the whirling engine of the hurricane, drawn into the vortex, lifted, cooled, its water precipitated as rain. This yields energy. The storm uses this energy to draw still more water-charged air from the rear, to condense its water, to obtain more energy. Doubtless a hurri-

cane, once started would pump the ocean dry except for the fact that it is broken up sooner or later by other air movements or drifts across a shore line and over a continent, where it stretches its following water carrier to the breaking point and dies, quite literally, of thirst.

Thus viewed, a hurricane is a veritable steam turbine, with everything going on inside it that goes on in the turbine. Astonishing but little appreciated is the tremendous amount of energy which such an atmospheric turbine can supply. Conservative calculations estimate it as more than a hundred billion horsepower. The Miami hurricane of 1926 blew for six days, which is by no means a record. Yet if the power which it generated could have been trapped and put to work it would have sufficed to run every dynamo, motor and steam engine in the world for twenty years. Small wonder that such a power generator thinks nothing of blowing away a few hundred ships or pushing over two or three cities.

But what starts this enormous turbine into rotation? How do hurricanes begin? No certain answer is possible, but it seems probable that almost anything can start them. All that is needed is some slight whirl in the atmosphere, a tendency to water condensation in its front right hand quadrant, the resultant liberation of energy and the progressive strengthening of the whirl. Its future growth is limited only by the ability of the vortex thus set up to feed itself with water from the oceanic boiler in its rear.

It is a common idea among meteorologists that the air next the water of the calm belts, or doldrums, becomes overheated, so that atmospheric equilibrium is disturbed. The layer of heated air rises through

the cooler and heavier layers, and sets up the initial whirl.

This theory is plausible enough, but it is not the only theory. In recent years meteorologists have heard much of what are called "polar fronts," a conception advocated by the distinguished Norwegian scientist Bjerknes. According to this conception many of the storms which afflict temperate latitudes are caused by air eddies at the edges of great masses of cold air which drift down periodically from the neighborhood of the Pole. Along the "fronts" of such displaced masses of cold polar air there is active atmospheric circulation, with many storms and vortices. It is not impossible that some of these may get far enough south to invade the doldrums and give birth to eddies that grow up into hurricanes. Two large air currents passing each other in opposite directions would have a similar eddy-forming effect. Even a ship afire in the doldrums might be enough to start an eddy and begin a hurricane. Violent hurricane-like air whirls have been observed over great fires ashore.

The year-by-year variations in the number and violence of hurricanes have been blamed on many things, from too much radio to the sunspots or the near approach of the planet Mars. To Mars and radio immediate acquittal is granted. They are not even accessories.

About sunspots it is not so certain. Years of maximum sunspot activity have been marked by numerous and violent hurricanes, but on the other hand some hurricanes, like that of Galveston in 1900 occurred in years when sunspots were unusually sparse. It is impossible that sunspots alone could cause the

hurricanes; what is more probable is that both they and the hurricanes are symptoms of some deep-seated disorder in the sun which intensifies its radiation.

The cyclonic storms which move every few days across the United States and which give its characteristics to the weather east of the Rockies and north of the Gulf States are in some ways small editions of the hurricanes. They are less violent, and there are more of them in a year.

Their lack of violence is probably explained by the lack of any large steam boiler to supply their power. There is no tropical water to drive them on. They must derive their energy from the moderately heated and moderately moist air of the mainland.

Nor is much known about their origin; much less, in fact, than is known about the origin of the West Indian cyclones. The cyclones that cross America begin somewhere over the North Pacific, southwest of Alaska. This portion of the ocean contains what meteorologists call a "permanent low"; that is, an area in which the air pressure is always or usually below normal. This permanent low is surrounded by the usual whirl of air. In some fashion this rather permanent "cyclone" in the Alaskan sea throws off other and smaller cyclones which then begin their cross-country careers, as though a giant pinwheel threw off smaller pinwheels which continued to revolve. Both the parent whirl and the smaller whirls are, of course, following the characteristic tendency of the wind to revolve.

The smaller cyclonic storms over Europe—which, like their brethren of America, are responsible for most of the European weather vagaries—are generated in a good deal the same fashion in the ocean

southeast of Greenland. The rest of their history is not unlike that of their relatives in the United States.

By far the most destructive storm is the tornado the whirling funnel-shaped terror of the prairies so often misnamed a cyclone. It is more destructive even than a hurricane because it centers the release of its energies on a smaller area. No one knows what the velocity of the wind in the whirl of a tornado may amount to. No instrument will measure it. Probably it is over three hundred miles an hour Its lifting force is sufficient to pick up and carry off planks, small houses and even human beings and animals. So great is the velocity of the wind in these whirls that splinters have been driven clear through solid boards, the speed of the splinter having been so great that it penetrated the board before it itself had time to be crushed. During a tornado-like waterspout at Calcutta, India, a cane of bamboo is reported to have been driven all the way through a six-foot mud wall faced on both sides with brick.

Such tornadoes are usually short-lived; the destructive path of the whirl along the ground averaging thirty to fifty miles. Some are known, however, to have persisted for several hundred miles It often happens that tornadoes arise in groups, half a dozen whirls being formed at about the same time and place. Most of the world's tornadoes occur in the United States but they happen occasionally almost everywhere. The annual average for the United States is about 100 and about 300 people are killed by them each average year.

St. Louis, Missouri, seems to be particularly cursed by tornadoes: not, perhaps, that the twisters are more

prevalent there than elsewhere but because St. Louis happens to be the largest city in the tornado belt and therefore the most vulnerable spot. One of the worst tornadoes in American history wrecked a good part of the town in May, 1896, killing 255 people. In September, 1927, another destroyed $15,000,000 worth of property, killed 85 people and injured 1,300. It took only five minutes for the tornado to cross the city and accomplish all that havoc!

Cutting a neat swath through the home section of the city, the tornado broke the roofs off houses or sliced off their walls. For days afterward people kept house inside two or three walls instead of four. Automobiles were overturned and blown against buildings. Telephone poles broke and festooned the sidewalks with wires. Street cars stood smashed and powerless. The noise, both of the storm and of its havoc, was terrific. An observer, watching the black funnel drive toward him, noticed white streaks across it. The streaks turned out to be boards from a tennis court backstop. When the tornado had finished with St. Louis it jumped the Mississippi and completed its work in Illinois.

The most destructive tornado in American history was that which swept over an unusually long path across Missouri, Illinois and Indiana, in March, 1925. It killed 695 people, injured 2,027, and destroyed $16,500,000 worth of property.

The great destruction wrought by tornadoes is due to the literal explosions of buildings, not to the force of the wind knocking them over. The center of the tornado is a partial vacuum caused by the centrifugal force of the rapid rotation. Whenever this central tube of partial vacuum passes over a house it removes

some of the air pressure on the outside. Houses are not built to stand such a strain nor can the air inside the house escape quickly enough through doors and windows. The house explodes, accordingly, just as a tomato or an eggplant with an unpunctured skin will explode when baked.

While little is known about the origin of tornadoes and the sources of their energy, the most plausible theory ascribes their creation to an air eddy formed by two masses of wind moving in opposite directions at high speed. When two trains pass each other the air between them is rolled over and over on a series of vertical axes, as may be seen from the dust which these eddies raise from the road bed. Two masses of drifting air would do the same thing. If conditions are right, tornadoes may be started.

The tornado belt of the middle-western United States is a place where conflicting air currents are unusually common. Along the eastern slope of the Rocky Mountains the winds have a general tendency to blow from north to south. Further east, along the Mississippi Valley, the tendency of the winds is to blow from south to north. Where these northward and southward winds rub shoulders is the place where tornadoes are more prevalent than anywhere else in the world.

Dust whirls in deserts or on hot, calm days in summer are like tornadoes so far as lifting power and center vacuum are concerned but are caused by the overheating of the air next the ground, which rises and sets up its tornado-like whirl. Forest fires sometimes cause similar whirls of great magnitude. It has been suggested that true tornadoes might originate in this fashion but that seems doubtful.

Chapter 18

CAUSES OF FLOODS

A FLOOD is simply the accumulation of more water than the flooded portion of the earth is able to dispose of. Which means, usually, that there has been too much rainfall in too short a time.

But excess rainfall, even when reinforced by millions of tons of melting snow, seldom succeeds in staging any very impressive flood by its own unaided efforts. Even cloudbursts and forty-day downpours, if they are to accomplish anything notable in the way of general washouts, need an accessory before the fact.

That accessory is the soil. After almost every serious flood it is found that the soil has combined with the rain to bring it about.

Three recent floods, of very different types, and in different parts of the world, will serve to explain the fundamental causes that make floods happen and how the soil connives with the rain for proper flood-making. They are: The Mississippi flood in the spring of 1927; the Vermont flood of November, 1927, and the London flood in January, 1928.

The Mississippi flood, while it was the simplest in its causes, was also the most widespread and destructive of the three. Even more than the others it depended on the complicity of the soil.

It would be difficult to say just when the Mississippi flood became a flood, but the crest was reached

at successive points on the lower river from April 8 to April 25, and the water did not subside to a safe level until late in July. The flood could therefore be said to have lasted for over two months.

But six months earlier, toward the end of September, 1926, the experts knew that a flood was coming. They could not tell how great it would be but some flood was reasonably certain; the experts knew the soil and the river and what they would do.

From the middle of August through September and into October there were unusually heavy rains throughout much of the Mississippi Valley. In the lower valley of the tributary Illinois River the floods were the greatest and most disastrous of record; not until the end of November did that river fall below flood stage. By this time the experts knew that only a rainfall slightly above normal during the next few months was needed to bring on a really notable flood. The flood signs continued. The lowest water in the rivers of the United States is normally in the months of October, November and December, but those months of 1926 found most of the Mississippi tributaries well above normal stages. Later there came great floods in the Tennessee and Cumberland rivers, and all that was left to doubt was the extent of the Mississippi flood that was sure to follow in the spring.

Snow had little to do with it; the greatest amount, contributed by flood stages on the Ohio, did not add one-half inch to the height of the main stream.

During the late winter and on through the spring, rains fell in excess of their normal amount. By April the entire drainage area of the Mississippi, some 1,250,000 square miles, showed a general excess. The

real flood, it became apparent, was still to come. It was also apparent that from Cairo, Illinois, southward, it would prove to be the greatest of all recorded floods in that area.

The facts confirmed the forecast. The river gauges showed record high levels. Only the breaking of levees along both banks prevented still higher stages. New Orleans was threatened with a general inundation but the levee was dynamited fourteen miles below the city, flooding the delta country and driving out the ranchers and trappers and fishermen who inhabited it. This was on April 25. The crevasse was widened by successive dynamitings but in the two weeks following the river at New Orleans fell only half a foot, so tremendous was the volume of water still pouring down. Not until May 15 did the river at New Orleans begin its final recession. Further rains made secondary floods at various points above New Orleans, and not until July 14 was the final flood stage recorded, at Baton Rouge. The last overflow water did not pass into the Gulf of Mexico until after August 1.

Meantime levees had been breaking everywhere, letting roaring sheets of water pour out over the flat farmlands and canebrakes. Whole towns had been under water for weeks, stock was drowned, human beings were rescued by river boats and a fleet of Coast Guard patrol boats sent from the Atlantic stations. In many of the places where the levees did not break, the river swarmed over them just the same. There was no stopping it; nothing could be done but look on.

According to reports by the Weather Bureau's able flood experts, notably Mr. H. C. Frankenfield, sixty-

six cubic miles of water were measured as discharged from the swollen river. The total area of lands overflowed by flood water was 18,268,780 acres, or 28,545 square miles.

It is a curious fact that in all the great Mississippi floods since 1897 there had been no loss of human life directly attributable to flood. The slow approach of the inundation can be seen many days in advance. Although the inhabitants of lands under the levees are so accustomed to being deluged that they often have to be removed forcibly, there is almost always time to do this. But the flood of 1927 proved an exception. A total of 313 lives were lost. The loss in crops, livestock, farm and other property, protection work, and suspension of business reached a total of almost three hundred million dollars and money is still being spent to make that total larger.

And more money yet will be spent on protection, much of it doubtfully effective. Taxpayers will sweat to raise the money, engineers will sweat over tables of logarithms, and laborers will sweat under bags of sand, and farmers will sweat when they see the sand-boil that heralds the beginning of a crevasse in their new levees.

"But Ol' Man River, he just keep rollin' along!"

What caused the flood? Not the rain. True there was an excess of it, but not enough to account for a flood of this magnitude, for the rain was spread over a period sufficiently long to let the river channels take it out to sea.

The great Mississippi Valley sponge caused the flood.

No building and loan association is this sponge, no charity carnival, no slur, even, on the "gimme gals"

of the valley. It is merely a designation for the thick layer of soil that covers the drainage area in the center of the Mississippi Valley.

The soil is full of pores and these pores will hold a lot of water. It happens that they hold more water in cold weather than they do in warm—a fact that is also true of sponges. A sponge will extract a greater volume of ice water than it will of boiling water, as can be demonstrated by squeezing its loads of water at both temperatures into measuring glasses.

The reason for this peculiarity of sponges has to do with certain forces called surface tensions, which forces control the thing called capillarity. These are the forces that pull water into small tubes no bigger than a hair, or water up into a towel when only the tip end is dipped. They are related to the forces that cause water to wet some things and refuse to wet others—greasy things, for example. These same forces are active in the soil, pulling all available water down into its pores. In cold weather the soil holds more water than in warm, other things being equal, because the forces that hold the water in it are stronger; just as they are in the cold sponge.

A layer of this sponge-soil three to twenty feet deep covers the millions of acres of the Mississippi Valley. In it at all times is stored an enormous quantity of water, which varies according to the amount of rain that falls. No matter what the rain or snow fall, however, there is always relatively more water in this soil in the winter than in the summer, because of its sponge-tendency based on the greater strength of capillarity—in the cold.

Like city reservoirs, the main function of this vast sponge is to hoard water and to dole it out as it is

needed—to serve as an equalizing reservoir for the rainfall. In the few countries where there is no soil, such as the rocky slopes of mountains, all the rain flows away immediately for there is no place to store it. If the Mississippi Valley were soil-less the channel of the river would be dry between rains and a raging torrent after every widespread shower.

Thus the chief cause of the terrific Mississippi flood of 1927 is laid bare. The preceding fall and winter had been exceptionally rainy in the Valley, just as they were almost everywhere else in the world. *When spring came the soil of the Valley* was already about as saturated as it could be. Since the early months of spring were also rainy there was no opportunity for the soil water to drain out. The warm days of April arrived, bringing more rain and melting what snows there were. Also the sun warmed the soil and the capillary forces released a lot of the stored water. All this water tried to run off at once. The result was the flood.

A great deal of unadulterated bunk and hokum is spread over the question of flood prevention and control by those who speak knowingly of the part that forests play. What effect forests may have lies in the fact that they preserve the soil and thus provide a thicker and more permanent sponge for water-holding purposes. But that does not mean that the forest soil holds the water permanently; capillarity works on that soil too and forces some of its water out when the warm weather comes, just the same.

Settlement of the Mississippi Valley has probably not affected its floods at all. It has merely made them more costly. The 1927 flood was the most destructive in history but it may not have been the

greatest. In colonial times, records show that the whole Valley was under water. Some of the Indian mounds, it has been suggested, were built as refuges from earlier floods, and they were so used in 1927.

The abnormal thing about more recent floods is man's attempt to stop them. To speak of "controlling" a river is nonsense. Rivers do what natural forces require. What should be meant by such phrase is some sort of compromise that will let the river do as it wishes and still leave man and his works alone. What the river wants, of course, is to get to the sea. Things like levees are more apt to get man in trouble than to "control" the river. Plans for Mississippi flood prevention must include by-passes and overflow channels, even more important than levees or dams. The thing to do is to help the river flow more directly on its seaward course.

The Vermont flood of last November illustrates another condition favorable to flood-making; that of sudden, heavy rains in a region not adapted to carry off the water. The Vermont soil was waterlogged, like that of the Mississippi Valley, but that factor was not so highly important. The main reason back of Vermont's difficulties was that for three days heavy rains poured over the Green Mountains, providing more water than the small stream beds could easily carry. The capacity of the storage reservoirs and earth dams so numerous in Vermont was overtaxed; the dam of a reservoir broke, and the narrow valleys, adapted to carrying only small streams of water, filled up and overflowed the towns.

Still different in its causes was the London flood of January, 1928. Because of an exceptionally high

tide the water in the estuary of the Thames backed up, as it has done at intervals for centuries. Gales in the North Sea and the Channel drove in the general direction of the mouth of the Thames and piled up still greater masses of water ahead of them. Meanwhile there had been heavy rains inland over the Thames Valley, and melting snows. The soil sponge of the river basin was overloaded and was draining some of its water into the river.

Neither flood tide nor heavy rains alone would have pushed the river over its banks into London. It took the combination of rain and tide and soil to make the inundation. And so with floods everywhere else; it is the combination of several factors that makes all the worst of them.

Just as the predicting of desirable floods was the first thing ever learnt about weather forecasting, back in early Babylon, so the prediction of dangerous ones is one of the most highly developed and most successful branches of weather forecasting today. In one sense, it is the easiest branch of the business, for the conditions that regulate the flow of water in rivers are quite well known and most of them, like rainfall, are easily measurable. The work of the Weather Bureau in predicting accurately what the stages of the river would be at various points during the latest Mississippi flood, reached an exceptionally high standard and was of unequalled importance in that long-drawn crisis.

Chapter 19

DUSTY SUNSETS

THE sky is almost terrifying, seen from the top of a high mountain or from a plane three or four miles up in the air. Instead of the accustomed blue, one stares into a pall of black—a dead, oppressive black even at noon. The friendly canopy, the most familiar thing in life, has vanished. One is stricken with the feeling that the world has changed. One stands in an alien and menacing universe, alone.

That blackness is the true sky. Only when seen through the earth's atmosphere is the sky blue. The atmosphere is the painter of all sky-scapes. The air and the dust are its pigments.

Without air and dust there would be no brilliant sunsets. No "rosy fingered dawn" would herald the morning, no gold and crimson and lavender glow would soften day into night. Instead, a blue-white, intolerable sun would course from one horizon to another like a spot of light on a black curtain.

The air makes the sky blue, it used to be said, because of the dust particles in it. Now it is known that while dust contributes to the celestial pigmentation, it is not alone the dust that blues the vault of heaven but the atoms of the air itself, the molecules of water vapor and all the other tiny atomic things that the air holds and hides.

All these particles operate to produce the blue color in substantially the same way—by what is tech-

nically called the "scattering" of light. Full details of this "scattering" would lead one into some of the darkest mazes of modern atomic theory, but something very like it can be illustrated simply.

If there floated in the air a lot of tiny spherical mirrors, like marbles coated with quicksilver and glass or like highly polished ball bearings, light rays of all kinds would be reflected in all directions by these mirror balls. Such a cloud of mirrors would be brilliantly illuminated when the sun shown on it. That part of the sky would be, in effect, one great mirror surface.

Imagine, now, that this cloud of mirror-balls instead of reflecting all light equally, reflects the different light rays differently. Suppose that the mirrors reflected only the blue rays at the spectrum, permitting the red rays to pass between the mirror balls or through their bodies undisturbed.

That would be a picture of the normal state of the atmosphere. The dust particles and the air atoms and the water molecules correspond to the mirror balls. They catch and reflect the blue light more than they do the red. The normal atmosphere is relatively opaque to blue light and relatively transparent to red light; the rays at the blue end of the spectrum are stopped by the air particles while those at the red end pass through. The blue rays which have been stopped are then reflected or "scattered" in all directions.

That is why the sky seems blue. The particles in the air catch the rays of light, filter out some of the blue rays and appear to be illuminated by these blue rays, as though they themselves shone with bluish light. It is the vast assemblage of these blue-lit

particles that is seen, not, as primitive peoples have imagined, some blue inverted bowl behind the transparent air.

Not all the blue rays are stopped thus by the air but enough of them fail to reach the surface of the earth so that sunlight seems yellowish or reddish when compared with the blue-white of electric arc lamps. The sunlight has been robbed of so many of its blue rays in passing through the atmosphere that their loss accentuates the red and yellow rays which passed through safely. On the top of a high mountain where the atmosphere has not yet been able to do much of this blue-robbing, the sun appears bluer or whiter than it does at sea level.

And on such heights the sky seems black instead of blue because there are so few air-particle mirrors between the sun and the eye. The blue rays of sunlight are still charging down toward the earth uncaught and unreflected. The sky is still unlit.

The red colors of sunset and sunrise are laid on by this same process of stealing the blue. When the sun is near the horizon, it is seen through a much thicker layer of air than at noon. This thicker air filters out virtually all of the blue rays, leaving the red and orange end of the spectrum almost alone in its glory.

Reflected from clouds, haze, fog or smoke, this red light of the setting sun is combined and shaded to give the pinks, and by contrast or mixture with the whites and blues of the clouds, the occasional green and lavender effects, some of which are produced by contrasts within the eye. Still other sunset colors are occasionally produced, apparently by a process like the splitting of light by a prism. At sea

there is sometimes a flash of brilliant green light just as the sun sets. Presumably it is caused by some such prismatic action.

When the air is exceptionally dusty or filled with the smoke of forest fires or loaded with other kinds of haze, even the noonday sun seems red. The cause is the same as that which makes the sunrise and sunset red—more blue-stealing particles in the air through which the sun's rays must shine.

The world was treated to two years of exceptionally beautiful sunrises and sunsets and to many red noons when, in 1883, the great volcano of Krakatoa, in the Straits of Sunda between Java and Sumatra, erupted with what is believed to have been the most violent volcanic explosion of historic times. The eruption blew into the air a cubic mile or so of finely powdered volcanic dust; that is, minute fragments of rock. This dust floated in the atmosphere for three or four years, spreading through the air over all the earth, thickening and blending the pigment with which sunrises and sunsets are painted.

An even more striking instance of air dust painting itself blue and other things red was the "Great Haze" of 1773. Beginning in May, there gradually spread over Europe a heavy veil of haze that looked like smoke. *Unlike smoke it did not blow away or wash* out of the air. Instead it grew mysteriously thicker. As always, the haze itself looked blue; as always, its effect was to make the sun look red. So thick was the haze in places that objects a mile or two away could not be seen.

An acrid smell went with the haze; a smell reputed to have caused a great epidemic of coughs and sneezes throughout Europe. Seldom has any terrestrial hap-

pening created more widespread terror. Nobody knew the cause of the haze, not even the scientific men of the time. The public, of course, considered it a curtain-raiser to the end of the world or where popular imagination could descend deeper, to something worse. Communal prayers were said in churches and public squares. Manifestations of mass hysteria were to be seen everywhere. Every violent demonstration that fright contrives was staged somewhere. The haze lasted well into the winter but man has no capacity for sustained terror and that part of the spectacle gradually wore off.

The cause of all the trouble, then unknown, has since been found. A few days earlier the volcano of Skaptar Jökul, in Iceland, had exploded and billions of tons of pulverized rock fragments had been blown into the air. These tiny volcanic particles had drifted over Europe and formed the terrifying haze. It was more spectacular than the haze from Krakatoa merely because Skaptar Jökul was closer.

Nature does not need a volcano to strew the air with particles and form a haze. Forest fires accomplish the same thing in miniature. Many people wonder, no doubt, why there are no longer the beautiful "Indian Summers" which have been described from the days of the New England colonists until after the Civil War.

The Indian Summer was a period of comparatively warm weather late in September, or early in October. A few warm days at this period is almost a worldwide phenomenon—Italians called it "Saint Teresa's Summer" and Germans blame it on Saint Martin—but it was not mere warmth that made America's Indian Summers noteworthy, it was their atmosphere.

The air was soft and blue and hazy. Sunsets and sunrises were the most beautiful of the year. At this season, following ancient custom, the Indians throughout the Appalachian Mountains and on the prairies of the Middle West burnt the grass and the underbrush as preparation for the next year's crops. Even after the Indians were driven westward the famous prairie fires persisted as accidents. Smoke from the widespread combustion was responsible for the haze of the Indian Summer. To-day there is no prairie grass to burn and forest fires are fought so that the Indian Summer has disappeared.

The normal dust of the air comes from a great variety of sources. Some of it is mere soil dust lifted by winds. Another continual constituent is volcanic dust, for volcanic eruptions are happening somewhere in the world nearly all the time. Fires, either natural or in furnaces, are another source of many kinds of dust particles. In practically all air dust, also, are various kinds of living creatures such as bacteria and yeast cells and pollen grains from flowers and the spores of moulds and bodies or skeletons of the microscopic plants called diatoms. Skeletons of diatoms found in air dust have been identified as coming from half-way round the earth, for the dust of the air may be blown thousands of miles before it settles forever.

There is iron in the air, too, and no one knows for sure where it comes from. The iron particles are never very plentiful in air dust but one or two very minute grains of the metal are almost always found in any cubic yard of air. They are sometimes called "Tissandier's spheres" after Gaston Tissandier, the famous French scientist who first studied them. It

is probable that they are fragments of iron meteors burnt to dust in the upper air.

Then there are the "blood rains" and "dust storms" which occur here and there about the world. "Blood rains" especially used to rouse a great deal of excitement in Europe before their cause was understood. The rain which falls has a pinkish tinge, as though it actually were diluted blood. When allowed to stand in a container it deposits a reddish mud. Every year or two there is such a blood rain in Italy. Occasionally they happen in southern France and in the Balkans. Their cause is reddish dust from the Sahara, as the German biologist Christian Ehrenberg first proved in 1847. Storms lift the reddish desert dust and blow it northward across the Mediterranean to be washed down by European rains.

Dust storms of similar character are not uncommon in the western United States. In their case, however, the dust of the country is yellow or gray, which makes the rain muddy instead of pink. In northern Europe there are occasionally "sulphur rains," which have in them not sulphur but the plentiful yellow pollen of pine trees.

The investigation of air dust is by no means a perfected thing. Not all varieties of air dust have been traced to their sources nor is it certain that every kind of dust in the air has even been discovered. There is need for a Wilson Bentley of the dust; an enthusiastic, gifted amateur who will collect and study and record details about the tiny particles with which the atmosphere is filled.

Such work might easily lead to results as interesting as the discoveries of Bentley about snowflakes

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or of Ferrel on winds. Nor is it too expensive or difficult a task for the amateur to undertake. All he needs is a fifty or sixty dollar microscope and a simple apparatus for collecting the dust.

There are many ways of collecting air dust, but the easiest is to drive a stream of moist air through a small hole and against a glass plate. An instrument for accomplishing this, described by the well-known air dust expert Dr. J. S. Owens, can be made at home in a few minutes. A hole about an eighth of an inch in diameter is bored in the bottom of an empty tin can, the top of which has been removed. The can is then fastened above a flat groove cut into a board, so there will be space to slip a glass microscope slide back of the hole in the can and with its glass surface about one eighth inch away. The glass slide must be wedged in place.

With a clean glass slide in position, the can is then placed so that its open top is toward the wind. On dry days the inside of the can must be moistened, preferably with a lining of felt soaked in warm water. Air blowing into the can expands and cools a little as it emerges from the hole at the rear. This condenses tiny water droplets on some of the dust particles and these stick to the glass slide. On removing the slide carefully, these can be examined under the microscope, compared with dust particles from known sources and identified.

Once in a while strange, unknown particles show up and then their identification requires much ingenuity and becomes a problem as devious and fascinating as anything in detective fiction.

Chapter 20

WHAT SUNSPOTS MEAN

AS will have been apparent from the beginning of this book, the sun is the organizer and director and prime mover of the whole weather business; the power that starts and moves the great weather engine of wind and rain. So many and varied are the cogs and gears and belts and pulleys turned by that power that, even if the power were constant, if it never diminished or increased, the study of which belt moves which wheel and why one cog turns another would still be complex enough to occupy a life-time.

But that power is not constant. It varies. It is weaker one day, stronger the next. The wheels do not run always at the same rate of speed. Complexity is still further complicated, in this weather business, by the fact that the sun is no steadily pulsating dynamo but is a variable star. Its variability is shown, among other things, by the phenomenon of sunspots.

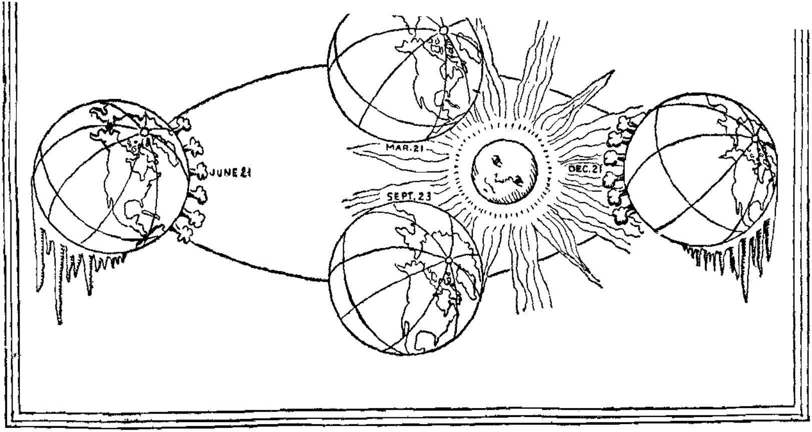
A great deal of speculation goes on these days about sunspots. So easy is the word to say and so obviously important is the sun that ordinary street chatter is full of references to these manifestations. It is too commonly taken for granted that the sunspots are mysterious but omnipotent dictators of everything terrestrial; that they cause wars and floods and famines; that they make or mar the health of

every living thing; and that, as is customary in all such half-considerings, there is something just a bit off-color and sinister about sunspots and their attitude toward the earth.

Some of which suppositions may be true, but the spots are not the dictators nor the source of these secret influences with their hints of malignity. They are merely a sign, a proof that the sun is a variable star.

One of the most significant discoveries of modern astronomy is that stars are often variable. Few of them seem variable to the unaided eye, although the variations of stars like Mira the Wonderful and Algol the Demon can be watched even without a telescope. But through powerful lenses it is apparent that, far from being the fixed and unchanging symbols of constancy that poets have acclaimed them, stars are perhaps the most continually and completely changing things in the universe. Not only do they move about the sky, but they wax and wane in brightness. They are born in clouds of gas and dust, they grow up to a hot and violent middle age, ultimately they die, suffering meanwhile with a sort of chronic intermittent fever that makes them blush and pale by turns.

Taking the temperature of these celestial fever patients is a work in which great numbers of astronomers have been engaged during the past few years. They have accepted the services of volunteer amateurs and have turned over to them the work of observing regularly one class of variable stars, the so-called long-period variables. Starting with seven members in 1911 under the leadership of Dr. William Tyler Olcott of Norwich, Connecticut, the As-



THE SUN WARMS NORTH AMERICA MOST STRONGLY WHEN IT IS THE FARTHEST AWAY.

The seasons are not due to varying distance of the sun from the earth but to the fact that the earth's axis is tilted. The sun and earth are closer to each other in the northern winter. That is why the seasons in

sociation of Variable Star Observers now numbers several hundred members. The only requisites for membership are the possession of a telescope at least three inches in diameter and enough enthusiasm to sit up at night and watch stars passing through their periodic fits of temperature.

The waxing and waning of stars was well known by the sixteenth century, but not until a few years ago did Professor E. C. Pickering, the brilliant American astronomer, diagnose the reasons for the peculiar behavior of one of them—Algol. The alternating periods of relative brightness and dullness were to be explained, he thought, by the assumption that Algol was really two stars which periodically eclipsed each other as they whirled about their mutual center of gravity. Within a short time this theory was proved by observations with the spectroscope.

Most of the variable stars, however, are not of this eclipsing type. They are single stars but that same remarkable instrument, the spectroscope, shows that they pulsate like great balloons, alternately expanding and contracting. Some of these are the long-period pets of the amateur astronomers; others are short-period acute fever patients still treated by the professionals. Both classes represent, it is thought, mere variations of the same fundamental phenomenon. What this phenomenon is it is one of astronomy's chief tasks to investigate.

The sun is just such a patient, suffering from a mild, long-term intermittent fever. As though it had measles, the sun's face is spotted when these fever spells come on. That makes the sunspots. But the most important matter is how the sun's inter-

ıittent fever affects its output of heat and light.

That the output of solar radiation does vary has ›een definitely proved by the work of the scientists ›f the Smithsonian Institution, and especially by Dr. ȝ. C. Abbott, now its Director. Proving this was a natter of tedious measurements and complicated nathematics. The first necessity was to establish what is called the "solar constant." This is supposed to represent the amount of solar energy continually received on earth on a definite area, with the elimination of incidental variations caused by the atmosphere. This constant would be easier to arrive at if observers could get outside the earth's atmosphere. As they cannot, errors due to the air have to be allowed for and corrected in various ways. So difficult are some of these necessary corrections that some scientists consider the exact measurement of the solar constant an impossibility.

Nevertheless, a great many measurements have been made and a satisfactory technique worked out. Observatories designed especially for making these measurements have been set up in Arizona, Chili and more recently in South Africa—each in a desert region where there is a minimum of atmospheric variation due to clouds and fogs.

The net result of all the measurements seems to indicate that the energy sent by the sun to the earth varies slightly from time to time, the variation perhaps amounting to 2 or 3 per cent. The laws which control this variation have not been discovered. All that is definitely known is that the sun seems a little hotter in some years than in others.

Discussion of the variable energy of the sun leads naturally to the question: what makes that energy?

The answer to that question astronomers now believe that they are beginning to glimpse.

The sun's heat was first ascribed to a slow contraction of its mass under the influence of its own gravity. Such compression would indeed heat the sun, as compression heats everything else. But this theory was disproved when Lord Kelvin, the great English physicist, calculated on this compression idea a past age for the sun of not over 50,000,000 years. That was far too short. The earth itself, it now seems, is at least two billion years old and more likely ten billion. The sun must be scores of billions of years old, perhaps hundreds of billions.

The problem then became that of finding something that can keep going the energy of the sun and of other stars for 100,000,000,000 years or more. Only one source of such energy has been imagined; the energy in the atoms of matter.

Atoms of radium, exploding, set free energy and thus enable the radium to keep a little warmer than its surroundings for hundreds of years. For a while some connection between radium and the sun was sought, but later it became apparent not only that all kinds of atoms are probably capable of producing energy *but that radium atoms are far too weak as* energy emitters to solve the question of solar energy. Nowadays, following largely the English astronomer, Dr. A. S. Eddington and his American colleague, Dr. H. N. Russell, scientists conclude that only one source now known or imagined could possibly keep the sun and stars going. That source is the annihilation of atoms of matter. One by one they must vanish utterly, leaving only energy behind.

That atoms can thus vanish has long been sus-

pected. The particles of electricity smaller even than atoms, electrons of negative electricity and protons of positive electricity, are believed able to come together, fuse, and cancel each other. Since it is these particles that build matter, when they vanish matter also has vanished. And theory indicates that their cancellation would set free vast amounts of energy, to appear as radiant energy precisely like that which the sun gives off.

The temperature at the heart of a star like the sun may be, Dr. Eddington calculates, as high as 60,000,000 or 70,000,000 degrees Fahrenheit. (The best furnaces on earth can only get up to some 9,000 degrees!) Even at a temperature far below that of the sun all matter would be gaseous and conditions probably suitable for the collision and cancelation of protons and electrons would exist.

Perhaps, when the sun was younger, it suffered more violent fevers than now or even pulsated like the star Mira, whose in and out beats have actually been measured by Professor Michelson's interferometer attached to the great telescope of the Mt. Wilson Observatory. With old age the sun's pulsation has either ceased or become so small that it is impossible to detect with certainty. But deep within the old body of our private star is some remnant of the pulsating force. Spasmodically it revives and raises the sun's temperature up until there is the fever-eruption of sunspots. Whether these best guesses of science are true or not, the fact is fortunate that the sun does not pulsate as violently as Mira, for an outburst like one of hers would burn everything on earth to cinders in a single blast of flame.

Even a solar variation so small as 2 or 3 per cent.

is enough to have important effects on the weather. If the great weather engine resembled man-made machinery it would have governors to check the speed or to increase it, as required. But there is no such governor on the sun or the terrestrial weather engine which it drives.

Only a very few of the probable effects of solar variation on the weather have been traced and explained. An increase of solar heat does not merely warm the earth. What seems to happen is that when the sun is hotter than usual the weather on earth is stormier. On the other hand when the sun is cooler the storms remain closer to the poles and the weather elsewhere on earth is less violent. But even this theory is still tentative. Whatever the effects, they are not simple and direct. More solar heat does not necessarily mean hotter weather, in New York or Zambezi or Medicine Hat.

The sunspots, it should be repeated, are nothing but symptoms. They are really not spots at all, neither are they black, although they look dark through the telescope. If a sunspot could be picked off the sun and set out in space it would seem almost as brilliant as a similar piece of unspotted sun. Sunspots merely look black by contrast against the brighter surface of the whole sun. In reality a sunspot is a great whirling storm on the sun, much like a cyclone on earth. Many of these whirls are large enough to enclose the whole earth in their darker centers without touching the globe anywhere. The centrifugal force of the whirl decreases the pressure at the center; this slightly cools the hot gas. Being cooled, the gas shines less brightly. That is why the

center of a sunspot is relatively dark. What causes the whole spinning vortex is unknown.

Chinese astronomers observed sunspots many centuries ago and for the past two hundred years or so records have been kept of their size and number. Thus has been discovered the fact that they vary according to the well-known cycle, also a cycle of terrestrial weather, averaging about eleven and a half years. But this cycle is not perfectly regular. Some intervals between maxima are shorter, others longer. Some of the maximum sunspot periods are greater than others. Some relation between this cycle and the weather is now accepted as a fact.

Apparently the intensity of sunlight increases at times of maximum sunspots; which is exactly the reverse of what one might expect. The spots are cooler than the general surface of the sun. It would seem that they ought to radiate less heat and make sunspot years cooler instead of hotter. The explanation of the paradox must be the fact that sunspots are symptoms of increased activity of the sun and that the unspotted area is giving off more heat than usual; enough to compensate for the cooling effect of the spots themselves and even to provide some additional heat.

This explanation is favored, too, by the recent discovery that in years of maximum sunspots there is a greater percentage of ultraviolet among the other rays in the slightly increased sunlight. The summers of 1927 and 1928 were sunspot years. They were also sunburn years. As many people who visited the seashore discovered to their dismay, one hour's sunlight produced two hours of ordinary sun-

burn. There are other confirmatory symptoms of solar effects on earth. Electric and magnetic phenomena on earth are known to vary in correspondence with the sun's fundamental cycle.

Efforts have been made, recently, to apply the facts of solar variation to long-range weather forecasting; with much promise for the future and some immediate success. With funds supplied by private subscription, Mr. H. H. Clayton of Massachusetts has made an excellent beginning toward such forecasts weeks or months in advance. Mr. Herbert Janvrin Browne, of Washington, D. C., issues regular commercial forecasts based on the solar variations plus consideration of heat storage in the oceans and of the ocean currents.

It is probable that many cyclic variations will be traced ultimately to variations in the sun and when that has happened weather may be predicted with assurance, months or even years ahead. Nothing that science could accomplish would be apt to have greater value to business but unfortunately a good many years of unpredictable weather are likely to intervene before that time arrives.

The increased emission of ultraviolet rays in sunspot years is why the sunspots are thought, or guessed, to have such startling effects on human behavior. Such an influence is not impossible. Sunburn is not the only thing ultraviolet gives to human beings; it has its moments also with their emotions and their health. For one thing, it stimulates most people and makes them nervous.

Such effects, if there are any, will probably vary with the climate. In relatively cold and cloudy climates such as Northern Europe and North Amer-

ica, the effect of increased ultraviolet rays might be to increase public excitability and to make the inhabitants physically more vigorous. A succession of high ultraviolet years might result in a vigorous overstimulated population in northern countries, far too prone to wars, revolutions or other disturbances.

Which is not to say, because this might happen, that it does happen. Nobody knows. Statistics assembled by enthusiastic sunspot fans are not particularly convincing. There is some sort of fish on the sunspot line, but the line is still out and the fish has neither been caught nor seen.

One thing about sunspots is reassuring to any one who might otherwise worry about his length of time on earth. The sunspot cycle of 11.5 years has been identified among the weather records left in trees and even in very ancient rocks. Which proves that whatever causes the variability of the sun, it has been varying just as it does now for a billion years or so. Admission that the sun is a variable star inevitably starts the rumor that it might go wrong and do something radical at any moment but those bits of Australian rock which show that the sun was staggering along in the same old way some 600,000,000 years ago are a cheerful reassurance for the future. It is better not to worry about the sun's health but to go to the beach and get a skinful of its rays.

Chapter 21

WEATHER'S RADIO VOICE

THE development of radio has had a two-fold connection with weather science. Radio, for one thing, is naturally useful to weather science, since it permits the understanding and in some degree the prediction of atmospheric conditions. Indeed, radio may one day become the chief dependence of weather forecasters—not in announcing their predictions but in collecting direct from the weather itself the data out of which such prophecies are made. On the other hand, knowledge of the weather is most important to radio for certain features of the weather control many factors of radio transmission.

This mutuality of interest is not at all strange, for the thing through which radio passes is a part of what makes weather. That thing is the air.

Radio is, of course, traffic by means of certain ether waves. Ether waves are somewhat unfortunately named on the familiar assumption that "empty space" consists of a mysterious, tenuous something called ether. This conception of ether is merely an hypothesis, adopted to explain the fact that things like light obviously do pass through empty space. But all this may be quite wrong. It may be, indeed modern theories hold it probable, that there is no such thing as ether and that the so-called waves are not really waves but mysterious

projectiles of some kind travelling through space as bullets do.

At any rate, ether waves, whether of light, radio or heat, do not depend primarily on the air for their transmission. But the air may impede their progress and certainly the air affects it. Radio waves are highly dependent on the conditions of the atmosphere; some conditions decrease the progress of the waves, others help it. The chief effect of the air on radio is, however, a benefit. It makes long distance transmission a possibility.

Like all other ether waves, the radio waves generated and broadcast from a station would ordinarily pass through space in all directions, decreasing in intensity as they went like the rays from a lamp. In order to produce a beam of light that will be powerful at a distance it is necessary to concentrate the rays and to send them out in a single direction, as with a searchlight. The same thing can be done with radio and is done by the modern "beam" methods, which focus the radio waves along relatively narrow paths.

But for ordinary long distance radio the circumstances are somewhat different. Light might be transmitted for considerable distances between a pair of mirrors. Rays sent out between one mirror set face upward and another one set face downward will be reflected back and forth from one to the other without being able to escape into space. Another way of sending light rays over reasonable distances would be by holding them in something especially adapted to conduct them—like the wires which conduct electricity. Rods made of quartz are good light conductors and through them light can be car-

ried to considerable distances and even around corners.

Both of these methods are applicable to the transmission of radio waves. Such transmission is made possible by the existence, fifty or sixty miles above the earth, of a stratum of very thin, vacuum-like gas which has come to be called the Heaviside Layer.

Oliver Heaviside, for whom this layer was named, is another example of the brilliant amateur who achieves great things in science. He was perhaps the world's greatest mathematician, but he never had a scientific vocation nor, indeed, much scientific recognition while he lived. He ran a bookstore in England and twenty years ago, for his amusement, he worked out the mathematical theories now used to organize and explain the whole science of transmission of alternating electric currents, also for a large part of the basic science of the telephone industry.

He reached the conclusion, on theoretical grounds, that there exists high in the air a layer of atmosphere which is especially favorable for the conducting of electricity. His conclusion has now been confirmed by actual experiments.

These experiments, conducted with controlled beams and broadcasts of radio waves, have shown that the Heaviside Layer lies several miles higher at night than in daytime, and that it varies somewhat in height and character according to the seasons. They may, if continued, show just what are the very thin gases of which it is composed.

Even now it is known that the gas atoms of the air at that elevation are highly electrified. Such masses of electrified gas conduct electric waves quite

as competently as do wires. When a long-distance radio wave is sent out, therefore, it rises until it encounters the Heaviside Layer, after which it proceeds along it half way round or all the way around the earth, as though the Layer were a metal plate conducting ordinary electricity. Also, because of the nature of ether waves, those of certain lengths may be reflected downward when they encounter the Layer, and on reaching the earth's surface reflected upward again—as though they were light waves reflected between two mirrors.

By one or both of these processes, long distance radio is made possible. If it were not for the Heaviside Layer radio waves would spread out in space and waste themselves uselessly; never curving around the earth to achieve the long distance transmission now so common.

The Heaviside Layer, however, is not a perfectly constant shell around the earth. It varies, as has been said, between day and night and between summer and winter. Apparently it sometimes falls into great convolutions or wrinkles. Also it would seem to be spotty; some parts of it are more highly electrified and conductive than others. These factors of variation naturally affect the details of radio transmission. They are believed to be responsible, for example, for much of the "fading"—the tendency of the messages to be strong and weak alternately, like the sound of a distant band through a gusty wind.

The sun causes most of these variations in the character of the Heaviside Layer. It would, of course! Whenever there is a chance for irregularity and general confusion in earthly things the

sun is found at work with its wavering intensity of energy.

The electrification of the gas in the Heaviside Layer must be continually renewed. This renewal, it is believed, comes mostly from the ultraviolet rays of sunlight. That is why the Layer changes its character and its elevation between seasons and between day and night; presumably, also, between seasons of different sunspot activity.

The next most important influence of the atmosphere on radio is through what is called static, and it is here that radio may begin to return to weather science the favor of the Heaviside Layer. All too many radio addicts have experienced static. It is the name for the series of noises, grunts and rumbles which may be distinguished from the outcries of radio tenors by the fact that not even the suspicion of a word can be heard. Static is what comes over the radio when even the hog expert is not quoting the price of shoulders in Chicago. It is, to most tastes, even less attractive than the ordinary radio "programme." Various listeners describe the noises of static as crashes, clicks, whispers, screams, etc. What they really hear are the voices of the weather.

When these noises have been studied they are sure to yield a tremendous amount of information about weather. When that time comes a man might sit in a soundproof room, listen at his radio receiver, and be able to tell with reasonable exactness what the weather is like a thousand miles away. But at present too little is known about what kinds of weather cause what kinds of static.

Here is one of the greatest opportunities that weather science has to offer to the amateur. Listen-

ing to the voices of the weather—which a more ancient generation would surely have held to be the voices of spirits—might be not only more profitable but in time more entertaining than listening to the usual run of songs and quips.

While the causes of most varieties of static are unknown some have been traced to their sources. Much is caused by lightning. A snowstorm produces a peculiar whispering. A nearby rainstorm sometimes makes a noise over the radio that sounds like dried peas rolling down a trough. Dr. L. W. Austen, radio expert of the United States Bureau of Standards, has traced other kinds of static to the cross-country advance of heat waves or cold waves. Captain Reginald Bureau of the French meteorological service has similarly traced certain kinds of European static to the advance of cyclonic storms from Iceland across England and western Europe. Experimenters in Texas have identified other static as caused by sand storms.

Undoubtedly every variety of weather broadcasts its voices in this way. All that is needed is study of these voices, and then their clicks and hisses will mean something more than Chinese curses.

Already one practical use has been made of these weather cries. They are used to forecast thunderstorms in cities. The arrival of a thunderstorm, darkening the city's sky, makes every one turn on the lights at once and that puts a sudden and heavy load on the electric light stations. Additional engines and dynamos must be started and it takes time to start them. One of the needs of a big city power company is to know in advance just when such a storm is to darken the city. The companies used to

keep watchers on roofs to predict when a thunderstorm was to arrive but two or three years ago the New York Edison Company worked out a method of doing this by radio.

An automatic apparatus picks up the signals of radio static sent out by a thunderstorm. As these signals become stronger it rings a warning bell. Attendants then start the additional dynamos.

According to a recent announcement the United States Navy is to utilize the static signals sent out by tropical hurricanes as a means of locating these hurricanes at sea and forecasting their progress and direction before they become dangerous.

These methods of radio weather forecasting will undoubtedly be greatly extended; indeed, within a decade or two their extension may be the chief activity of weather experts. It is curious that most of the developments of weather knowledge by means of the radio have been the work of electrical experts rather than weather men, but this should not be construed as suggesting that the scientists of the Weather Bureau are asleep at the barometer. That organization must proceed according to methods which have already been shown to produce worthwhile results; for these are still the most practical methods. It takes all the Bureau's time and men and money to do what it can about the weather with established methods, so that there is little opportunity to experiment with such new and untried devices as radio.

Solar disturbances naturally affect radio greatly, and it is interesting to note that radio broadcasting was almost killed off by sunspot activity around 1925. When broadcasting was developed suddenly

about three years before this, it happened that the earth was passing through a period of minimum solar disturbance. There was relatively little static and the earth's atmosphere was relatively stable. As time went on the solar disturbance and the resultant static increased. Between 1925 and 1927 radio conditions became almost unbearable. Long distance transmission was increasingly difficult, more and bigger static developed, and only the continual invention of new and improved apparatus enabled the infant to survive. If the ingenuity of radio engineers had not kept pace with the deterioration of radio's atmospheric pathway, broadcasting would have died an unlamented death. Then sunspots and solar activity began to decrease, radio conditions bettered, and more favorable conditions may be expected to last until 1933 or 1934, when the upswing of the next sunspot cycle will begin.

Radio, sunspots and abnormal weather have, of course, many interrelations. But for one reason or another the causes and effects in this case seem to have got mixed in many minds that should know better. The result is the occasional allegations, uttered by newspaper writers, scientists, and even by people of more importance, to the effect that the tremendous outpouring of radio waves all over the world is causing bad weather. There are, of course, plenty of radio waves. Always there is plenty of bad weather somewhere. Both are due partly to solar excitement. There the connection ceases. But even the commodore in command of a mammoth ocean liner quite soberly told ship news reporters the imagined secret that radio waves caused the rainy spring of 1928.

When one considers what tremendous amounts of radio energy are broadcast continually into the atmosphere by thunderstorms it becomes apparent that the minute, drop-in-the-bucket addition from all the radio stations in the world could not add one mile per hour to the world's winds or one hogshead of water to its rain.

Chapter 22

WIND AND WAVE

WEATHER, to a sailor, means wind. Rain and drought, heat and cold mean nothing to him other than comfort or discomfort. His business is solely that of getting somewhere and of not losing his life or the ship in the getting.

Nevertheless, the weather is in one sense more important to him than it is to the farmer, and in days before steam the weather was even more important to the sailor than it is now.

One aspect of that importance is the fact that weather at sea is far more violent than it is ashore. The same kinds of weather occur at sea, but each kind is worse. A calm at sea is a deader calm than on land. A storm at sea is much more of a storm.

The tropical cyclones of the sea and the cyclonic storms of the United States are the same character of whirling wind; they differ not in kind but in degree. Yet what a difference! From Jonah to Conrad the description of a storm at sea, its terrors, its impressiveness, the feeling of helplessness which it inspires, has been one of the main standbys of the literary artisan. Indeed, nothing that man can experience is more frightening or awesome, unless it be a thunderstorm about him on a mountain top or in aircraft. And if he be in a small boat in the midst of a sea storm the chances are that no land storm even at high altitudes will ever impress him so greatly.

As if to compensate for this extra violence which it hurls on mariners, the weather at sea makes a point of being simple and easy to predict. It accomplishes this concession by being more typical, by omitting variations and by sticking pretty close to rules. The hurricane at sea follows a more regular course than does the hurricane on land. The thunderstorm at sea is also more typical—and incidentally is about the only phase of sea weather that is less violent than its land counterpart. The cause of a thunderstorm is overheated air at the bottom and there is less likely to be much of this overheated air next to the waves.

The reason why sea weather is simpler is the mere converse of the statement that land weather is more complicated. The continents are a great annoyance to weather. They stick mountains up into the air and force air currents to twist around them. On the flat of the sea the air currents can go about their business with much less hindrance. Nor is there overheated land to cause thunderstorms and other abnormal weather phases; the ocean currents follow a steady course and what they do to weather they do at much the same time and place year in and year out.

About the only product of sea weather which that of the land cannot duplicate is the waves; and even this exclusive sea-weather work follows maritime traits by being violent in effect and simple in cause. Waves are no doubt the chief reason why sea storms are so terrifying and dangerous yet their mechanism is far simpler than that of the lightest summer shower on land.

Any neophyte of science who is willing to sac-

rifice his table manners briefly—and science expects stern devotion and exacts her burnt offerings—can produce waves in exactly the way they are produced at sea by blowing across a cup of coffee. Ripples are created by the friction of the breath, roll across the coffee and crash against the sides of the cup in small-scale replica of the style in which ocean waves crash against the rock-bound coast. And when the blowing stops the ripples still chase each other back and forth, only gradually dying away.

This literal tempest in a coffee cup is a real model of what happens when the wind blows hard at sea. Waves are created by the friction of the wind, extend over great areas outside that in which the wind blows and roll on for some time after the wind has died down.

That is the explanation of why the sea is called restless, and for once a poetic appellation is true. The chances are that there never is a time anywhere when the sea has not some remnants of waves on it. Somewhere the wind is blowing and the waves it creates extend their action hundreds or perhaps thousands of miles away from the area of the storm.

One thing about waves is not universally understood. Watching from the seashore the procession of waves rolling in, it would appear that one wave slides forward to take the place of the wave behind it, and that of course, is the case. But the sense in which it is true is not always clear to every one. The forward motion of waves is not the motion of the actual particles of water; the particles in one wave do not move forward while they are moving up and down, as does a boat on their surface. Except for some slight movement of particles at the surface,

like those of spray, the particles which make up a wave stay in relatively the same spot above the sea bottom. They merely vibrate up and down as though they were kinks chasing along a rope. The "Witching Waves" device in amusement parks is more truly a wave machine than many of its riders realize. Its semi-flexible floor of metal is pushed up into waves by eccentric rollers underneath it; a given point on its floor stays in the same place horizontally despite its up and down undulation.

Certain special waves, called tidal waves, are merely extremely big ones that may be caused by a force other than that of the wind. The results of that force on the sea may be seen thousands of miles away and frequently do tremendous damage. The tidal wave created by the explosion of the volcano of Krakatoa was perceived 3,000 miles away. On the coasts of Java and Sumatra it killed some 30,000 people. Earthquakes frequently produce tidal waves especially when the earthquake occurs under the ocean.

Still other tidal waves which strike occasionally against the coasts of China and Japan are caused by typhoons. The typhoon, it will be remembered, is a tropical cyclone, quite similar to the hurricanes of the Caribbean. But the typhoon tidal waves are apparently not caused by wind but by actual changes in the level of the ocean brought about by the passage of the partial vacuum in the center of the storm. Like the eccentric rollers beneath the floor of the amusement-park ride, the partial vacuum lifts the surface of the ocean into a bulge. The bulge progresses with the movement of the storm. So long as it stays at sea the bulge does no harm; in fact, it

is not even perceptible, for the change of level amounts to only a few inches or at most to two or three feet.

But in rushing along the surface under the "eye" of the typhoon, the bulge acquires enormous momentum as does a moving mass of any kind. When the storm center crosses the coast line the bulge runs into the edge of the land and its momentum results in a great wave which rushes far up on the shore. Apparently that is the chief cause of the tidal waves of the Asiatic coast. Something of the same sort seems to have occurred, although with less violence, when the Florida hurricane of 1926 hit Miami.

It must be admitted, however, that many of these sudden high waves which rush up on the shore every once in a while all over the world are still unexplained. Earthquakes, changes in air pressure or volcanic explosions account for some of them but not for all.

There is nothing tidal about them, in the sense that the tides cause them or that they cause the tides. The tides are bulges created in the ocean on opposite sides of the earth by the attraction of the moon, as though a line were run from the moon to one tide and on through the center of the earth to the other tide. As the earth revolves these bulges remain more or less stationary but to any one on earth they appear, of course, to move. Both bulges seem to make a complete transit of the earth in twenty-four hours. When the shore of any part of the world, in the course of its daily revolution, runs into one of these oceanic bulges the tide seems to rise. As the bulge is left behind the tide seems to fall. Details of the rise and fall at any given point are

greatly affected by the interaction between the tidal bulges and the topography of the shore and the ocean bottom. In addition, there are effects of the varying distance between the earth and the moon, of the attractions of the sun and the planets, and other factors, all of which complicate the actual tidal movements and heights.

With one possible exception, the tides are not related to the weather. That exception is the alteration of the average level of the ocean by long-continued and widespread winds which tilt the surface of the ocean slightly as the surface of coffee may be tilted by a good long blow across the cup. The tilt in the surface of the ocean is commonly only a few inches but even this slight excess of water on one side may affect the daily bulges of the tides. When the tilt adds water to the bulge flood tides may rise higher on shore than they would otherwise do. It was such continued winds on the North Sea and the English Channel which tilted the water, raised the flood tides, backed up the estuary of the Thames and flooded London in January, 1928.

Seafarers naturally need to know everything possible not only about tides but about the weather, for the very good reason that their lives more often than not depend on it. Weather helps or hinders their business of travel even more than it does the business of farmers and, in addition, personal safety is at stake. Furthermore, sailors are one set of people who can do something about weather. They cannot change it but they can escape it.

This combination of dependence on weather and ability to do something about it results in the fact that seafarers have been always far more weather-

wise than other classes of men; that and the further fact that forecasting at sea is exceptionally easy because the weather is simpler.

The worst sea storms are probably the hurricanes yet no ship's captain who knows his business ever runs into a hurricane without warning. All he needs is a barometer and the ability to apply a rule-of-thumb or two which he may get from books. The barometer begins to fall; when it falls in a certain way the captain knows that it is actuated by the change of air pressure from a hurricane. By the changing direction of the wind he knows which way the hurricane is approaching. It is even possible for him to tell the approximate distance of the center of the storm and a good deal about its speed.

Because of the rotation of the earth all such storms revolve in the same direction; clockwise in the northern hemisphere and counter clockwise in the southern one. Since the rotation is always the same and since the air pressure toward the center of the whirl decreases according to relatively simple laws, all that the captain has to do is to watch his barometer and his wind direction for a few hours. Then he can make a quite accurate guess as to where his ship lies with relation to the fringes of the hurricane. Lee shores and other dangers permitting, he can then run in such a direction as to avoid much of the blow.

Simple as such sea-weather prediction is, it promises to be made still easier by the perfection of radio methods of forecasting. It is now a very general rule on the North Atlantic and soon will be the rule everywhere else for captains of ships at sea to exchange information by radio as to weather conditions which each captain observes. There are so

many ships on the North Atlantic at all times that a complete collection of weather data from them would permit the preparation of a weather map almost as accurate as that made for the United States or for Europe. No doubt the time will come when such a weather map will be prepared by international cooperation and issued daily by radio to all ships at sea.

A number of tentative beginnings have already been made. Some of the largest ships now prepare weather maps for themselves on information received by radio, the maps being made aboard ship. The United States Weather Bureau collects data from ship captains and issues occasional maps for the North Atlantic. These maps are of no use for day-by-day forecasting, for they are prepared long after the weather conditions set forth, but they add gradually to knowledge of weather conditions. By a radio method similar to television oceanic weather maps could be prepared at a central station on shore and sent out to ships at sea; both sending and receiving being automatic and the apparatus aboard ship actually drawing the map.

Some such devices will eventually be installed on all larger ships, so that a master at sea will have before him on his chart table every day a map showing the weather conditions of the ocean on which he is travelling, just as he now keeps charts that show the coasts and depths of water and steamer lanes.

Chapter 23

AVIATORS' AIR

WHEN men first began to travel in the third dimension they became aware of many things which they might have known before, but which for the first time borrowed the weight of practical importance. The air, they found, is not the smooth, uniform "ambient" of the imagination; instead, it is rough, bumpy, unequal in texture. It had mountains, and valleys, ridges and chasms—a whole topography of its own.

But the topography changes. It moves. A land hill stays put for a few thousand years at least but an air hill dashes around; up, down, forward, back, or sidewise at all sorts of speeds. There is no mapping it; its contours do not last long enough.

Its topography is the weather—the general circulation of the atmosphere, the whirling storms, the boiling cloud-columns, the cold currents, the hot ones, the "highs" and "lows" of air pressure. Its perils are those of weather; the fogs and hurricanes and snows and lightnings. It became necessary for flying men to learn this weather topography, as necessary as was the learning of geography by walking men.

As aviation progresses this necessity becomes greater. A short flight traverses weather that is constant enough to be known in advance. A long flight, since weather topography changes, is inevitably a dive into the unknown.

That is even now the case. Aviation has made demands on weather science, in some particulars, that weather science cannot meet. It is preparing to meet some of them; day by day data are being accumulated which will result in the formulation of laws by which the movements of air topography may be predicted; already weather forecasts have proved highly valuable to trans-oceanic fliers.

But aviation is impatient. With the lower air only half conquered, the flying men are speculating on heights four times as high as any man has yet reached. In those upper levels perhaps the topography will be easier, perhaps the hills will flatten out. Most important of all, if the higher topography moves perhaps it will move more regularly. Aviation would like to find these conditions in the higher air because flying might be more efficient there and tremendously faster. It has asked weather science what to hope for, far above.

Weather science has part of the answer and it is favorable. Fliers will do well to leave behind the bumpy lower air. Now it is up to aviation, in turn, to answer its question: Will man ever be able, mechanically, to travel thirty miles above the ground?

The "air holes" and "bumpy air" of which aviators complain are not, of course, real holes or bumps in the air. That is merely what they feel like when a plane hits them. A plane may fall two or three hundred feet in a few seconds when it hits a "hole."

What really happens is that the plane runs into a rapidly descending current of air which carries the ship down with it. An ascending current will lift a plane almost as suddenly. It has hit a bump. Such

bumps and holes are at their worst over continents, and especially over mountains, precisely where there is the least room to navigate, for they are increased by such local disturbances as the overheating of the ground, the blasts of winds against mountains and the like.

But the airman's greatest need, especially for long distance flights is advance knowledge of storms. In half a dozen countries plans are under way for making weather forecasts especially for airmen. The most comprehensive scheme so far put into effect is that operated by the weather station at the great air terminal at Croydon, near London. Here weather reports are received continually by wire and radio from European landing fields, from pilots of air liners in flight and from all other available sources. A staff of experts studies these reports, prepares a weather map of Europe which is corrected hourly and furnishes for every pilot expecting to take off on one of the main air routes a special forecast of what he may expect to encounter on his trip. This service has been in operation so short a time that its methods and utilities are changing constantly, but some adaptation of the system will no doubt become the standard for similar weather stations all over the world.

Weather science applied to air travel is the same as that on the ground, except that forecasts have to include conditions throughout two or three miles of air instead of mere ground-surface conditions. The United States Weather Bureau has experimented with a series of weather maps one above the other according to conditions in eight superposed strata of the air, so that the pilot can have a kind of layercake picture

of the atmosphere. But American weather experts are still trying to work out the best way of making weather information practically available for aviation. Progress has probably been faster in Europe but this may be because commercial aviation there is further advanced.

Excellent forecasts for airmen attempting the transatlantic flight have already been prepared, however, by Dr. J. H. Kimball and his associates in the New York City office of the Weather Bureau. Lindbergh, Byrd, Miss Earhart's party and others have reported that Dr. Kimball's special forecasts were accurate and valuable. There remains, however, a great difficulty in obtaining the essential data from ships at sea for adequate funds are not available for the necessary radio service. Betterment of such oceanic forecasts will be inevitable with wider use of radio reports and more complete recording of weather conditions by ships.

As soon as transatlantic flights became almost a commonplace it was noticed amid the general huzzaing that westward air crossings of that ocean are much more difficult than those from west to east. When it is remembered that the eastward-moving cyclones of the United States control not only the continental weather but much of that over the ocean the reason for this becomes clear. The whole weather picture of North America and of the North Atlantic continually shifts eastward. A flyer going east flies with the weather. If he could fly fast enough he might leave with good weather and stay with it all the way—almost. But the weather picture does not move at any definite speed. Also, it may fade out and disappear. Nevertheless, flying

thus with the weather has tremendous advantages over flying against it, which is what the westward flier must do. He is like a man trying to make way against a parade instead of with it. He must buck new kinds of weather all the way.

The highest flights ever made by aviators have reached only about seven miles and so short were these adventurers' stay at this altitude and so desperate their situation that almost nothing of value to the study of the upper air was gained. Altitudes of three or four miles are reached more commonly, but not much can be learned there about still higher levels. Small hydrogen-filled balloons carrying recording instruments have been sent on up as high as twenty miles and records of these have been valuable.

But the air that aviation hopes some day to move into lies thirty or forty miles above the earth! What science knows about it and about other levels above and just below it has been learned principally by radio waves, light rays, meteors and imagination. Most of the theories about the upper layers of the air are matters of deduction rather than of instruments.

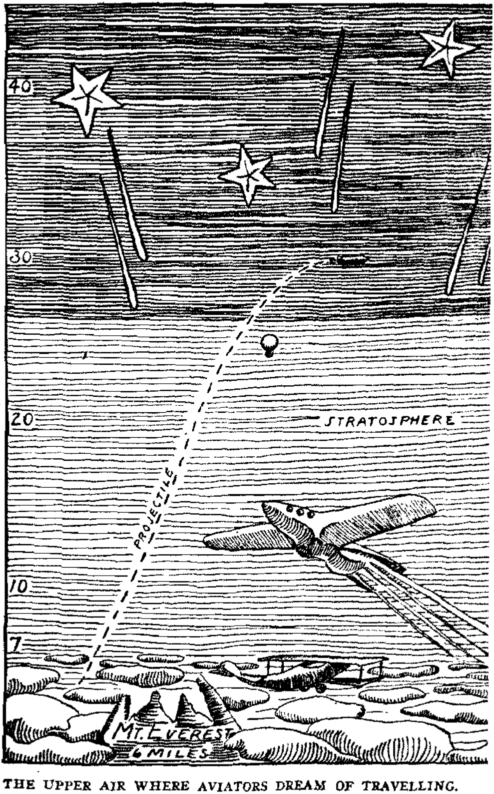
The flights of test balloons do indicate, however, three layers of air, more or less separate. The bottom two are reasonably well known. The lowest, the ordinary atmosphere in which we live, extends about seven miles upward, its upper level rising a bit higher in summer than in winter. This is the air that is stirred by storms, the air in which ride all but the thinnest and highest clouds, the air in which present-day aviation travels.

As soon as the highly variable temperatures near

the ground have been left behind the air temperature drops more or less regularly, about 15 degrees Fahrenheit for every mile of rise. Seven or eight miles up the temperature is about 75 degrees, Fahrenheit, below zero and the air pressure is equivalent to a height of about four inches in the mercury barometer; normally this is about thirty inches at sea level.

Above this ordinary atmosphere is the remarkable region called the "stratosphere." Throughout its fifteen or twenty miles of additional height the air temperature remains curiously constant at about 75 degrees below zero. No sounding balloon has ever traversed this stratosphere altogether but from the few hundred little balloons that have entered it—they are watched through telescopes during their flights and sometimes recovered with their records of pressure, temperature and altitude—it has been guessed that the stratosphere has a system of winds of its own, not unlike the trade wind system of the lower atmosphere, perhaps changing in direction with the seasons but blowing in different directions from the lower air currents and probably blowing faster. So little is known about these stratosphere winds, however, that no very definite conclusions can be drawn. It has been suggested that these upper winds be utilized by sending aircraft up into them, to be floated around the earth like sailing ships on the sea, but this suggestion is too far ahead of real knowledge of the prevailing winds of the stratosphere to be taken very seriously.

From study of meteors and of the Aurora Borealis and some other evidence it is imagined that some 23 to 25 miles above the ground the stratosphere



THE UPPER AIR WHERE AVIATORS DREAM OF TRAVELLING.

Man has never risen above the lower six or seven miles of air. S balloons, with instruments, have risen into the stratosphere. Pe rocket aircraft will one day fly there.

ceases and the third of the earth's blankets of air begins. This uppermost zone is probably much warmer than the stratosphere. It may be even warmer than the surface of the earth.

But its warmth will not resemble the warmth of anything with which man is familiar. There is too little of it; the air is too thin. Calculations indicate that just below the third layer, about twenty-five miles up, the amount of air still left is so slight that its barometric pressure is not over one-hundredth of an inch of mercury—one three-thousandth of the pressure at sea level. At one hundred miles up, within the warmer layer of the third zone, the air pressure is probably not one-hundredth of this upper stratosphere pressure. For all practical purposes this is a vacuum but it still retains enough air to have electrical properties, for the Aurora flames to heights even greater. Enough air remains in this third zone, also, to cause meteors to burn up by its friction.

It is within this third zone that aviation expects its future long-distance paths to lie. So thin is its air that in it aircraft capable of 100 miles an hour in the lowest atmosphere make ten or twenty times that speed.

This very thinness of air, however, would make navigation of the third air zone impossible for craft of any type in use to-day. Airplanes are able to fly because of the air's density. The "lift" of the air under their wings is what holds them up. The resistance of the air against their whirling propellers is what drags them ahead just as ships are pushed by the revolution of their screws against the water.

Automobiles move because of the friction of their wheels against the road; even horses and men move

by means of the friction of their feet pushing against the ground. Airplanes are built to push similarly against the resistance of the atmosphere and they cannot do without it. Still, the friction of the atmosphere slows them up. If some means could be devised by which tightly enclosed vehicles carrying their own internal air could fly without utilizing air repulsion then the third level of the atmosphere would be an ideal place for travel.

That method of propulsion has been found. Its principle is that of the rocket. Rockets do not need anything to push against. They kick themselves along by the gases which they emit.

Action and reaction are equal and opposite, as Sir Isaac Newton pointed out. Action is illustrated by the forward flight of a bullet from a gun. Reaction is the backward kick of the gun. Nor is air necessary for this action and reaction. A blank cartridge fired from a revolver in vacuum kicks the revolver backward just as if a bullet had been fired from it in air. The gas discharged from the barrel, instead of the bullet, represents the action. The action of a rocket is similar. Powder or some other explosive fired from it, even in vacuum, kicks the rocket ahead.

In April, 1928, a human being was fired through the air by a rocket for the first time in history. The vehicle was a German racing car driven by twelve rocket tubes. When the driver, Herr K. C. Volkhart—a pioneer and hero if there ever was one—pulled the lever that ignited the first of the rockets a cloud of white hot gas exploded from the tube and the car vanished in its own smoke. Half a mile away it stopped and Herr Volkhart climbed out of it, almost stunned by the shock of starting but other-

wise unhurt. The car had attained a speed of sixty miles an hour in eight seconds. A month later another rocket car reached 120 miles an hour in the same time. A similar rocket car built to run on railway rails probably reached an even greater speed but wrecked itself before the test was over. A cat, which was the only passenger, had vanished. Perhaps it was de-materialized by the speed; perhaps it merely ran away.

The application of the rocket idea to aircraft was conceived by an American, Professor R. H. Goddard of Clark University, some twenty years ago. He has designed a rocket capable of rising perhaps a hundred miles into the air, without a passenger, and of bringing back to the earth samples of the highly electrified gases which are thought to be the only atmosphere at such altitudes.

The theory of the rocket car, even for human passengers, is perfectly sound but putting the theory into practice may not be easy. There is no known fuel light enough in weight and at the same time energetic enough to send the rocket to really great heights. German designers suggest using an initial charge of explosive to send it high enough in the air so that it could drift along for a time and then glide down to earth as any motorless glider would do. It is suggested that European mails might be shot thus to India or Australia in craft without passengers, guided to their landings by radio.

Whatever may develop practically from these ideas, it is a fact that the air pressure in the upper levels of the atmosphere is very low and that is the fact of chief importance in considering the idea of rocket-propelled cars. Unquestionably that would

make for greater speed. The long-range cannon with which the Germans shelled Paris in 1918 probably sent its shells into the stratosphere. These guns proved to have even greater range than the German ballistic experts had counted on and it was plausibly argued that the excess range was gained by decreased air resistance fifteen or twenty miles up.

Whatever the problems and the still-unsuspected difficulties of rocket-power and upper-level navigation, the fact remains that the first seven miles of the earth's atmosphere look very low indeed to weather scientists and perhaps to the real geniuses of aviation, no matter what stunt-flyers may think about it. Those far upper reaches are the places for flying, they believe, and they hope to make such super-flying a reality.

Chapter 24

FACTS FOR FARMERS

CONSIDERING their ancient and direct connection, it is passing strange that so little is known about the effects of weather on agriculture. That weather makes or breaks crops everybody knows, and that is about all anybody knows. Causes, mechanisms, results; indeed, some of the most fundamental facts of the relation of weather to farming, are deep mysteries whose solution has scarcely been undertaken.

For once weather science is not at fault. The Babylonians invented that science as an essential to the growing of their crops and their discoveries have been developed and added to until meteorology is now a highly organized branch of knowledge, but the science of plant physiology is less than one human generation old.

As its name implies, this is the science which deals with the living activities of plants. It is concerned with the processes which go on inside the bodies of plants, the things which correspond to the digestion, circulation, nervous actions and other mechanisms of the animal body. It is only just beginning to learn what these plant processes are; how the weather affects them is a fundamental part of the study because only by observing weather effects may clues to many phases of plant growth be discovered.

As the average person sees it, frosts and droughts

are about the only phases of weather which have any effect on agriculture worth mentioning. Even the farmer is apt to share this opinion. Yet such spectacular blights are relatively rare and unimportant. Infinitely more important for the practical business of the world is the influence of the weather, in small and scarcely noticeable ways, on what might be called the good health and vigorous life of plants.

It is just as though medical science observed only the effects of freezing and thirst on human beings, ignoring all other phases of physiology, pathology and hygiene.

Plants are as much subject to climate as human beings are; perhaps more so. Unsuitable weather induces illness in plants; decreases their vital activities and their efficiency in the business of living just as it interferes with the brain or body work of the human being. Nor can plants go to California or the Riviera for their health or spend a hard winter in Florida. A plant must stay and take its weather standing up and few of the human weapons against weather are available for its use.

One reason why the relations of plant life to weather are in such a stage of relative mystery is the fact that the cultivated plants in which man is chiefly interested are so different from the plants which Nature originally designed. For his own purposes man has created a long list of plant monstrosities with characteristics quite different from those of natural, wild plants. If medical science had to deal with a corresponding race of human freaks it would need to learn a lot that so far it doesn't know. Its chief concern might be, for example, with such rare diseases as actinomycosis or aspergillosis,

to correspond to the mould and yeast diseases of plants.

As to plant freaks, the ordinary peach is a case in point. All that Nature demands of the peach species is that it persist. Wild peach trees, therefore, need produce only a few peaches. And these fruits need only enough flesh and that just sweet enough to persuade an animal to eat it and so scatter the seed. Quantity and quality in a peach are desired by Nature but the standards of quantity and quality are quite different from those set up by man. Man wants as much of the fruit as possible. He wants it as big and as sweet and as juicy as it can be made. For thousands of years, therefore, farmers have selected and bred and developed peaches to produce more fruit to a tree, with more flesh on each seed and with more sugar in that flesh.

The history of other cultivated plants is similar. Wheat has been developed to produce more seed than Nature has any need of, for man eats that seed. Agricultural plants resemble freaks and monsters in many ways. They grow faster than Nature intended, or with greater development of leaves, or with increased production of substances such as sugar or indigo. In every case the change is one that man, not Nature, has desired.

The physiology of agricultural plants is obviously quite different from that of wild plants. Similar differences in body and mind exist between domestic and wild animals. The white rat, which has become a laboratory domestic animal carefully fed and cared for, has already lost most of the mental shrewdness and ability to take care of itself possessed by the highly intelligent wild species from which it is de-

rived. Nor could a domestic cow take care of herself in a jungle full of wild animals, as wild Indian cattle can do.

Thus dealing with abnormalities, it is easy to understand the difficulties that lie in the path of the infant science of plant physiology. And since so few of the internal processes of these plant freaks are adequately known it is obviously impossible to describe how minor changes of weather affect their health and efficiency. It is known, however, that such effects exist and that they are reflected, among other ways, in statistics.

Comparisons of records over long terms of years show correspondences between the prices of agricultural products and the weather or between the weather and any other index of world prosperity. These correspondences are by no means simple, nor could they be expected to be simple when two such complicated factors as plants and weather must be dealt with. Nevertheless, relationships have been shown to exist and the precise nature of these relationships it is now one chief duty of agricultural science to discover.

If it were known what weight to give the various factors it would be quite possible, the authors believe, to draw a curve of good and bad times which would parallel a curve of weather conditions. This opinion reaches, furthermore, to the prophecy that in the not-distant future it will be possible to draw such a curve in advance, so that good times and hard times will be predicted on the basis of what will then be known about weather forecasting.

A few basic facts about plant physiology and weather have already been established. It has been

discovered, for example, that not only do plants refuse to grow at certain extremes of temperature but that each intermediate temperature has, for each species of plant, a certain definite growth rate. There is an "optimum" or best growth rate for any plant under specified conditions. There is an optimum rate, furthermore, for almost any specific activity of a plant, such as the production of seed by wheat. Accordingly, as the temperature in the wheat fields of the world changes with the weather the minute processes which are feeding mankind go on faster or slower depending on the temperature's relation to these optimum requirements of wheat and rice and potatoes and other plants.

Similar general laws govern the matter of moisture. Too much moisture in agricultural soils prevents the normal activity of plant roots. The soil is water-logged; the soil air driven out of its pores; the plant roots strangle and may be killed. Whether or not the plant dies, its efficiency is impaired by excess soil water and its activity falls below its best. There is an optimum of soil moisture as there is of temperature. Moisture either above or below the optimum hinders the plant's work.

These optima differ with each species of plant. They differ with each kind of soil. They differ with the characteristics which man desires the plant to possess. So many varieties of agricultural plants are there and so many varieties of soil and weather conditions must they meet that there is probably no more complex and variegated study in the world of science than that of plant physiology. And little by little the complications are increased.

There is the matter of light. Until the past cen-

tury the effect of the sun on plants was considered solely a matter of temperature. Now it is known that the light rays and the ultraviolet rays of sunlight definitely and directly determine the growth of plants and of certain substances in them.

The fundamental chemical reaction which provides all the food for the world, for example, is that called photosynthesis. It consists of the production of the simple form of sugar called glucose out of carbon dioxide gas and water. The process is conducted by tiny green granules in plant leaves called chloroplasts. It is these green granules which give foliage its color.

Light is essential for this reaction. That is one reason why the production of food materials by plants is so much greater in summer than in winter. The days are longer and more light strikes the plants. But this photosynthesis reaction, like other properties of the plant, is gravely affected by the temperature, by the available water supply, by the texture and composition of the soil and by still other factors. All these influences are so interrelated that the effect of one depends on the effects of others. They are called dependent variables. There are so many of them that it is no wonder they are scarcely understood; even the recognition of their existence is a big step forward.

True there is little in all this that is of immediate help to the farmer. A close knowledge of plant physiology and of weather would help the most "practical" farmer living, but he cannot be expected, perhaps, to study such things for himself. They must be worked out for him by some one else and fed him in predigested, capsular form. Even then

he must first unlearn a lot of agricultural folklore taught him by his forefathers.

On the other hand, much of this knowledge is continually put in practice by the farmer without his knowing it. After one fashion or another he uses this knowledge when he determines the kind of crops he will sow, the dates of plowing and of harvesting, the farm lands that he will buy or sell. He studies the weather of his neighborhood and the plant growth qualities of his soil and he applies the fruits of that study—or he ceases to farm.

One special use to which what is already known about agricultural weather science may be put is in the purchase of a farm. It is important to study the record of local weather for past years. Weather, as has been explained, is not merely inconstant but tends to change in cycles; series of cold, wet years follow series of warm, dry years. It is advisable, therefore, to look up weather records for a considerable term of years before deciding what the future weather in any locality is apt to be. The recent weather may have been adequately moist but behind that may have been dry years, and such years will come again. They may be only a year or two in the future, waiting to wipe out the beginning profits which will not yet have paid for the farm.

This matter of the limits of past variation in weather is one all too often neglected in undertaking agricultural projects. Yet such information is of paramount importance in such widely different methods of agriculture as dry farming and fruit farming.

Dry farming is the name for a type of agriculture adapted to parts of the Dakotas and to other regions

where there is some rainfall but not enough for ordinary farming methods. Ways of handling and cultivating the soil have been found to conserve the soil moisture and to enable plants to use it efficiently. Some lands with deficient rainfall can be cultivated economically in these ways.

Where the little available rain is so carefully used it is obvious that the exact amount of rainfall is even more important than where precipitation is more plentiful. So many inches of rain are necessary for a given crop in a given region and on a given soil. Anything less is disastrous. By experience the quantities of rain absolutely necessary for the life of any given crop in a given region are reasonably well known.

When dry farming first became common, some twenty years ago, many people started out at it in regions which at that time were suitable enough because there had just been a series of rather wet years. But much of the land thus hopefully tilled for the first time proved climatically unsuitable. The weather cycle changed, dry years succeeded, thousands of dry farmers went broke. The catastrophe, for in some places it quite justified that word, could have been avoided by the study of weather records over a longer period, for these records would have shown other series of dry years in the past.

Much the same thing has happened frequently in Florida, California and other fruit-growing regions, but in this case the enemy is not drought but frost. After a few warm years without frosts a number of optimists always try to extend fruit culture into regions which then seem to be safe but which in colder years are apt to be frost bitten. All

too often the new fruit growers start at the very end of a warm cycle and the swift recurrence of a series of cold years bring irreparable disaster. This sort of thing has happened twice in parts of Florida and California. It need happen nowhere, for long and reasonably accurate weather records are now available for nearly every farming region in North America. To start any agricultural project without carefully studying these records is inexcusable carelessness.

Chapter 25

WEATHER COMFORT

THE first question roused by mention of any strange climate is always: Is it comfortable? Its healthfulness, its stimulating qualities, its suitability for various lines of endeavor are also of interest and eventually the questioning gets around to them. But all personal considerations about the characteristic weather of any place begin—and only too often end—with its effect on human comfort.

Why are such places as California, Florida and the Riviera famous as pleasure resorts? Why do so many people spend so much time and money going to them and living in them? Not because their climates are healthy; it is not so very certain, in fact, that they are healthy. Not because their climates are good for people who have to work; energy may be better produced by quite other kinds of climate. Not so very much because they are beautiful—whatever their addicts may think—because Tierra del Fuego and Greenland and Devil's Island are also beautiful.

The favorite climates are those that offer a maximum of human comfort. Their "comfort index" is high. That is why people like to live in them.

This comfort-quality of a climate is something that ought to be measured, just as are measured the temperature and rainfall and other phases of weather which determine the suitability of a region for farming. Its suitability for human farming is even more important.

Real estate agents and hotel keepers and transportation companies know that if a climate is not comfortable it has no excuse for existence, yet, so far as measuring the comfort qualities of average annual weather is concerned, even the point of view is a new one. Professor C. F. Brooks of Clark University was the first to suggest, we believe, that climate and weather should be classified in accordance with their contributions to human comfort.

An excellent idea and one that realtors should adopt, if only for the purpose of awing prospective purchasers with statistics about comparative-comfort indices instead of the unconvincing bird's-eye view. To be sure, nobody knows precisely what it is in weather that really determines human comfort or what kinds of weather give the most of it, but such lack of knowledge would never bother a good real estate salesman.

Too great heat, cold or humidity are the reverse of comfortable; everybody dislikes extremes. That is only the smallest part of the question. What kinds and conditions of heat and temperature are the most comfortable? How do various individuals react? What kinds of individuals? Does an individual react to these conditions in the same way all the time? Are the conditions interdependent or independent? Is one temperature always the most comfortable, or does its comfort depend on the humidity and other factors?

A series of questions, again, which can be answered only partially. Like the relation of weather to plant life, almost nothing is known of the details of weather's relation to human life and least of all to the considerations of human life that make for com-

fort. It is one more of those subjects about whick science has scarcely more than discovered that there is something to discover.

The fact that there are such subjects, incidentally is the answer to the pessimists—invariably person who know little of any subject—who complain tha science is all over, that everything worth while ha been discovered and classified and pickled in form aldehyde. Twenty years ago collegians were told tha astronomy was finished, that nothing remained to d but bury the dead. Yet astronomy, since that time has been completely revolutionized by discoverie greater than any ever made before. Much the sam thing is said even now of weather science—a scienc at its very beginning if ever there was one an which is probably on the verge of discoveries no yet imagined.

Among the few things known about what make weather comfortable or not, two are reasonably sur One, which rests on ordinary observation, is tha man is an adaptable animal. That is shown by th fact that he can live in extremes of temperature an like it; some 200 degrees separate the coldest in habited spot on earth from the hottest. That ma is adaptable means that he is made comfortable b what he is used to. Nor is it merely a matter of rac and of long evolution, such as the negro's preferenc for hot climates. It is an individual matter as wel as witness the cases of people born in temperat zones who live so long in the tropics that they com to dislike the winters of their former homes.

The matter of human adaptability raises still mo questions. *How far can adaptation by habit go?* I there a certain standard common to all humans th

lies beneath all adaptations by habit? And so on. The questions are there to be answered but the answers are not yet.

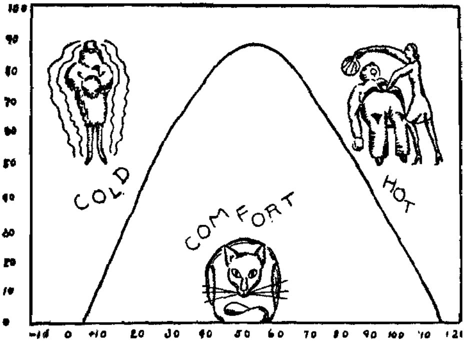
The second thing reasonably sure about the relation of weather to comfort is a conclusion reached by the British sanitary expert, Dr. Leonard Hill. The chief single factor in human comfort, he finds, is the rate at which heat is lost by the body. His idea is beautifully simple.

The human body is a heat engine. It is like a locomotive except that the heat is generated after the machine moves instead of before. The energy content of the food, converted into chemical form, is carried to the muscle fibres. Here, in a manner not fully understood, the chemical energy is converted into *motion* and *heat*. The *motion* moves the muscles; that is, the fibers contract. The heat warms the body.

Ultimately the heat of the body escapes into surrounding space. Human beings, like all warm-blooded animals, are therefore veritable stoves. They are continually warming the space around them and if the heat does not escape regularly and sufficiently into space the body is not fulfilling its nature —and is uncomfortable.

That is Dr. Hill's reason why the rate of loss of heat is so important to comfort. If heat is lost too rapidly—faster than it is supplied by muscular *movement and the oxidation of food*—the body cools to the point where it is uncomfortable. If the surrounding air, on the other hand, is too hot the body is likewise uncomfortable because its heat is not lost fast enough.

That also explains why humid weather seems un-



HOW TO KNOW WHEN YOU OUGHT TO BE COMFORTABLE

Human comfort is fixed by the loss of heat from the body. The scale across the bottom of this chart is the *temperature in Fahrenheit degrees.* The *upright scale* is the relative humidity; the percentage to which the air is saturated with water vapor. At temperatures and humidities inside the dome-shaped curve the average human being is comfortable. Outside it on the right he is too hot. High temperature may be made comfortable by low humidity, because that increases the evaporation of perspiration and the loss of heat from the body. Outside the left hand side of the dome people are too cold because their bodies then lose too much heat instead of too little.

comfortably warm—why it really isn't the heat; it's the humidity. The body's safety valve for letting out excess heat is perspiration. Perspiration evaporates faster in dry air and in moving air. Evaporation cools the body. In humid air evaporation is slower, bodily heat is lost at a correspondingly lower rate and discomfort increases.

Dry air works similarly to make extremes of heat comfortable. People put in a good day's work in the western deserts with the thermometer at 120 degrees in the shade, because the desert air is dry and perspiration evaporates immediately. Temperatures of 130 degrees in Death Valley are almost comfortable, so dry is the air.

Dr. Hill's idea also explains why winds can be comfortable or uncomfortable. In summer a brisk breeze is comfortable because it carries away the moisture-saturated air next to the moist skin and allows more perspiration to evaporate. A winter wind is uncomfortable for the opposite reason: it blows against the body and cools it too much, the rate of heat loss is too high. It is commonly said that the bitter cold of certain high regions is not so uncomfortable because it is a "dry cold" as compared with the supposedly moister cold of seacoasts and lowlands. The main difference is wind, not dryness. In the high lands the coldest days are almost always days of still air, the rate of heat loss is less and the cold does not seem so uncomfortable.

Although this principle of rate of heat loss has been reduced by some investigators to figures of temperatures, humidity and so on, the basis of most of these is mere assumption. Such figures must vary according to the individual, his health, the amount

of muscular work done, the food eaten and many other factors. Therefore just what amounts of heat-loss per minute constitute too much or too little are still unknown. Dr. Hill has devised an instrument called the "katathermometer" which is supposed to measure the rate at which heat will be lost by the human body in any place and any weather but it has had relatively little use.

It is not straining the imagination too much to say that the time may come when outdoor climates all over the earth and the atmospheres inside all public buildings will be rated according to their average power of taking away heat from the human body instead of according to mere temperature. Then there will be a basis for a real comfort index. Its use may extend to medical practice and physicians may classify their patients according to how many calories of heat they need to loose each day per square foot of skin area. They will be "high heat producers" or "low heat producers" instead of being known by their blood pressures or their hemoglobin indices. Then a doctor will know a good deal more thoroughly what he is doing when he prescribes a change of climate.

Weird as such semi-prophecies may seem, it should be remembered that predictions about safety matches would have seemed even weirder a century ago. The thing that people live for is, after all, their comfort. Comfort will be more and more appreciated as people shed, one after another, the delusions that they live for something else.

The soundness of the loss-of-heat theory is proved by its application to known conditions of discomfort. There is the notion, for example, that crowded rooms

accumulate "bad air" because of exhalations of carbon dioxide gas. When it was discovered that human beings breathe out this gas it was at once assumed that its collection in crowded rooms was what brought discomfort. Systems of ventilation are still based on the assumption that air must be changed frequently in order to carry away this gaseous "poison."

Which is another specimen of bunk. Carbon dioxide gas is not a poison. The air may contain as much as ten per cent. of it without doing anything to humans other than to make them breathe a little faster. Even this faster breathing is merely a normal reaction on a nerve center in the brain and is neither dangerous nor related in the remotest way to poisoning. The other ancient idea that some mysterious and dangerous "effluvium" is given off by the body or lungs is similar foolishness. It ranks with the asafetida-bag specific against disease, yet thousands of people believe it.

The fact is that the only cause of discomfort in crowded and "close" rooms is this same rate of loss of heat from the body. It happens that the body gives off continually water as well as heat. In a crowded room both accumulate and keep the air moist as well as warm; evaporation slows up, and the rate of loss of heat is lowered for everybody in the room. If the air in the room be cooled by a refrigerating coil, which also freezes much of the moisture out of the air in the form of frost, the air will remain quite comfortable for hours. The exhaustion of the oxygen and the discharge of carbon dioxide gas are processes far too slow to have any

appreciable effect under ordinary conditions. Even in the Black Hole of Calcutta the victims could never have suffocated. Heat stroke or fright probably killed those who died. If every one imprisoned there had sat down and kept quiet, so that their bodies would have produced a minimum of heat, there would have been plenty of air for every one.

The body really needs little air. Indian fakirs remain sealed in coffins for many hours, because a coffin with a body in it still contains enough air to last for about two days, provided the occupant lies absolutely quiet and so uses a minimum of air.

What the body really needs is the opportunity to get rid of heat, and that is the secret of efficient ventilating systems which control the heat-removing power of air by cooling it and drying it at the same time. The refrigerating systems so commonly installed by theatres and motion picture houses owe most of the comfort they produce to the fact that refrigeration dries air as well as cools it. Such systems are slowly being introduced into factories, for it has been discovered that comfortable workmen are more efficient workmen. In a short time adaptations of such systems will be used in homes. It is just as foolish to suffer indoors from the "heat" of summer as it would be to return to old-fashioned unheated houses in winter. Homes of the future will be warmed and moistened in winter and cooled and dried in summer.

Going out into the uncontrolled open air from such a summer house one ought logically to take off his clothes, just as one puts on more clothes on going out in the winter. For it will be understood by then, perhaps, that the essential thing is to keep the rate

of loss of heat at the point which induces the maximum of comfort.

Some people "feel" the heat or the cold more than others because people differ in the amounts of heat that they produce and therefore in the amounts which must continually be got rid of. People differ, too, in their personal mechanisms for getting rid of heat. The area of skin in proportion to weight has much to do with it. Fat people are troubled by hot weather, for example, not because their fat keeps the heat inside but because they have more body per square foot of skin. Almost all the heat that escapes from the body is brought to the skin by the blood and fat affects its escape very little. Fat people have too little "radiating surface," as a heating engineer would say, and for that reason they may not make the super-comfortable winter bedfellows that song and story have them.

So far all this has been about matters of comfort. Where comfort leaves off and efficiency begins is a line that has not yet been ruled. Wherever it lies, it is surely fine as a hair. Comfort is so commonly dissociated from work, in the mind, that it is inconceivable to many people that they be mentioned in the same breath. Yet comfort, it is beginning to be understood, has a very definite relation to matters of productive energy. Too much comfort—better said, certain conditions of comfort—unquestionably retard energy, but too little comfort retards it likewise or at least misdirects it. Just where the twain shall meet has not yet been decided but so far as the weather affects efficiency at least one thing has been tentatively established, that is the supposed "optimum" or "best" conditions for human work.

Many investigations have been made as to the optimum temperature for factory, mental and other kinds of labor. Most of them, unfortunately, were made before the rule of rate of loss of heat was appreciated and hence they can no longer be relied on.

It is said, for example, that a temperature of about 75 degrees, Fahrenheit, is best for the activity of the white race; that the optimum for brain workers is slightly higher and that for laborers a bit lower than this mean; and that the optimum is higher for negroes. Such figures have little meaning. The optimum, if any, is lower for laborers merely because their bodies are producing more heat and need a higher rate of heat loss for comfort and efficiency. The mere temperature of one's surroundings has little to do with either comfort or efficiency, since it is only one factor out of several that affect the rate of loss of heat. A perspiring girl in a bathing suit on a summer day may be perfectly comfortable in a temperature well over 100. The same girl in a humid kitchen wearing a dress impervious to air movement may be highly uncomfortable at a temperature of 80.

Out of the investigations carried on before the rate of loss of heat was appreciated, one real fact about the effects of weather on efficiency has emerged. That is the relation of civilization to storminess, a relation deduced by Professor Ellsworth Huntington of Yale.

Professor Huntington drew maps of world civilization, indicating the regions in which civilization has risen highest. Then he drew maps of relative storminess, indicating places where the storms are most

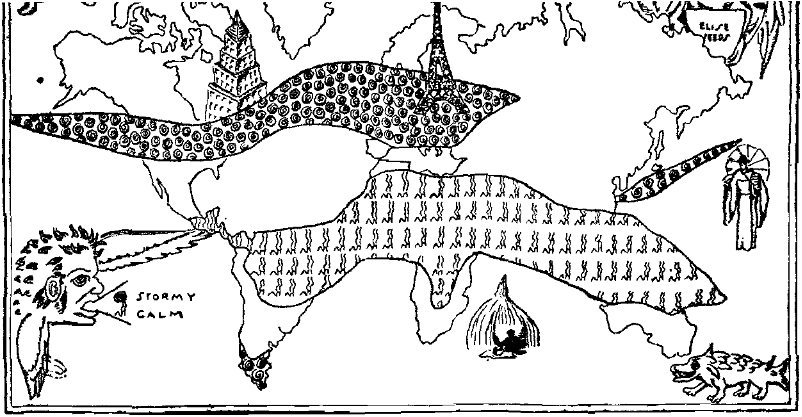
frequent and where the consequent weather changes are most marked. The maps virtually duplicated each other. Stormy areas turned out to be civilized areas.

The essence of the evidence that supports this conclusion is that human energy is increased by relatively frequent changes of weather. Alternations of temperature or perhaps of other weather elements seem to stimulate the human brain and body, so that efficiency is highest and civilization rises to its loftiest peaks in countries which have changeable weather.

Why this is so has not yet been discovered. Nor have all experts accepted Professor Huntington's conclusions. But there seems to be a large measure of something in it, and it may be assumed that a variable climate like that of England or of the Eastern United States is a blessing in disguise—much too good a disguise, most people will agree. The next step is to find out why storminess makes for energy.

The converse of this idea tends in a way to prove it. Southern California has a comfortable climate and one that is little changeable. Certainly it is not stimulating. People tend to "let down" there. Hence there may be two kinds of ideal climate. Rich people and lazy people, who neither need nor wish to accomplish anything more in their lives, will find the purely comfortable climate their optimum. Those still mastered by ambition will prefer the stimulating climate, even if it is less comfortable.

Day-by-day variations in the stimulating factor of the weather are probably at work as well as the long-term factors reflected in Professor Huntington's maps. And there has been some effort to run these factors down. One of the present authors



PROOF THAT CIVILIZATION SEEMS TO DO BEST WHERE WEATHER LEAVES SOMETHING TO BE DESIRED.

The map shows two belts: one of storminess, the other of mild weather and calms. The high civilizations of Europe, North America and Japan match exactly with the stormy belt.

once made an investigation to see what the weather had to do with the state of mind on getting up in the morning: whether the cheerful leap out of bed or the grouchy wrong-side exit had any relation to the weather. But the volunteer observers were not numerous enough and the results were entirely negative. But that disproved nothing, either, so there is still opportunity for some amateur scientist to make a name for himself as discoverer of how weather factors affect morning dispositions.

Nor should it be thought that such a discovery would be humorous or even futile. Weather affects comfort and comfort affects efficiency, and what is there that affects both—and everything else—more powerfully than the state of one's temper on arising?

Chapter 26

CLIMATE AND HEALTH

FOR at least three thousand years it has been a fixed belief of mankind that weather has a definite, direct effect on health and one that is paramount among external influences. So firmly is this idea embedded in the consciousness of the race that it seldom receives any thought; it is accepted as a fact beyond consideration, like other canons of the faith. People seem to be born believing it.

Here and there in history, to be sure, some one has taken the trouble to mention the matter and to add the weight of print to the dogma. But as with art, immortality, beauty and so many other important things, discussion is apt to confine itself to strident assertion and to the promulgation of unprovable theories, with a fine minimum of actual scientific investigation.

In spite of this the idea has much to recommend it. There is usually a grain of truth in folk-belief and there is much more than a grain in this one. Besides, some effects of weather on health are real, demonstrable and well-known.

But how direct the effects are and how important; just what they are and how they work and why; what anybody knows about these things sums up, under critical analysis, to almost nothing. Admitting that the weather has some effect on health, there is still room for the hard-boiled skepticism of the tough-minded as to what these effects are.

Weather has, at least, an effect on death. According to Professor Ellsworth Huntington, weather caused the deaths of 75,000 people in the United States in two months of 1927.

The winter of 1926 was open and warm, he says, until the middle of February. Then came an unusually cold and inclement period which lasted till the middle of April. This led to an unusually large number of colds, much pneumonia and some influenza as well as other illnesses. The result was that in the spring weeks the number of deaths was about 75,000 greater than normal. Again in June, 1925, a sudden hot spell over much of the United States caused the number of deaths to be between fifteen and sixteen thousand above the normal for that period.

Professor Huntington is a foremost meteorologist, explorer, anthropologist and geographer. Much more than most experts he knows what he is talking about. Furthermore, most people, scientists or laymen, would agree with him that inclement weather caused these deaths. But who can prove it? The relation is highly probable but the details of how extreme weather kills people are still elusive.

Surer ground underlies the effects of one weather element—light—on health; perhaps a more important effect than any other single thing except food. The discovery of the influence of ultraviolet rays on the well-being of the human body is one of the great achievements of modern medicine. Just what are the details of these effects is still imperfectly known but experts in human climatology now accept as unquestionable the conclusion that a small, reasonably regular dose of ultraviolet rays is essential to human

health. Man cannot live always in the dark and remain well.

But whether it is only the ultraviolet rays of sunlight which affect man's health or whether other rays are concerned also is not known. Nor is it known to what extent the darkening of the skin which ultraviolet rays produce is related to matters of health. Negro blackness, it is commonly assumed, is caused by long residence in tropical countries where the ultraviolet rays are intense and is protective, for too much ultraviolet is unquestionably dangerous. This is highly probable but again it is not proven.

Few subjects have aroused more discussion than these probable relations between light, health and the color of the skin; relations which take form and argument among the white race in the discussions about differences between blonds and brunets. There are some deep-seated characteristics of blonds and brunets which everybody knows to be different, at least on the average. Members of the blond races of northern Europe tend to be energetic, optimistic, practical, far-sighted planners and good managers. It is from these blond northerners that England has drawn the thousands of able governors and generals and conquerors who have won the widespread British Empire and have ruled it.

The brunet races of southern Europe, on the other hand, tend to be mercurial in temperament—first elated and then depressed. These dark-skinned people tend also to be imaginative; to be so logical that they push things to extremes instead of stopping short at the point of practical common sense which the blond northerner always recognizes, and to live much more in the moment than blonds do, with small

thought for the future. Brunet people tend to be lazy and energetic by turns, working hard for a little while and then loafing altogether. The slower but more consistent type of worker is characteristic of the blonds.

Scientists admit many exceptions to these rules, which are intended to apply only to averages of large numbers of people. Furthermore, the scientists who study these racial matters do not pretend to say which of the racial types is superior to the other, or indeed that either is superior. The greater ability of the blond for sustained effort may be balanced by the greater brilliance and imagination of the brunet. Science takes no sides between the advocates of Nordic supremacy and those who urge the greater claims of the south Europeans. Science notices merely that the two racial groups are different and tries to discover how these differences have come about.

There is almost universal scientific agreement to ascribe these mental differences of the two racial groups to climate, perhaps chiefly to the variations in light.

Dr. Charles E. Woodruff, of New York City, who has devoted a lifetime to the study of the effects of light on the human body and on other living organisms, traces in detail the relation between the places where blond races now live on the earth and the places where fog or cloud shuts off most of the sunlight from the earth. In those countries, he says, which average less than 1,250 hours of sunshine each year the blonds flourish. Such countries are Norway, Sweden, parts of northern Germany and the northern parts of Ireland and Scotland.

On the other hand, in countries where the sunlight

totals more than 1,700 hours a year blond peoples tend to die out, even if migration takes them into these sunny lands. Brunets are different. For them the sun is necessary to happiness. When there are more than 2,500 hours of sunshine a year the dark-skinned, black-eyed, black-haired people do well; the blonds die out or move out, often within a single generation.

Among all the hundreds of racial groups living on earth there are only a few exceptions; for example, the dark-haired Eskimos who live in cold and cloudy Arctic lands. These exceptions are explainable on other grounds; the Eskimos, because they are presumably recent migrants, who have occupied the Arctic countries only for a few thousand years and have not yet experienced the full bleaching effects of these lands. Some scientists imagine that the Eskimos are descendants of the famous Cro-Magnon race of prehistoric France, a race of hunters driven northward not long before historic times by the invasion of grain-growing, agricultural people from Asia.

People who have spent much time in desert countries, like the hot and sunlit mesas of the southwestern United States, know that some individuals who come to the desert suffer soon from what is called "desert madness." They have been known to hide in basements under piles of rugs, driven by an uncontrollable impulse to escape, somehow, from the unendurable brilliance of the light outside. It is worth noting that these unfortunates whom the desert ruins and drives out are nearly all blonds.

It is probable that the human race, when it originated, as scientists think, somewhere in the highlands of Central Asia, was of a light brown or deep yellow

color. From this original human center migrations have gone out, millennium after millennium, to people other continents. One stream of migrants filtered into Africa. On the way to that continent and after they reached it this branch of the original yellow-brown race experienced some of the most intense and continuous sunlight of the earth. It turned their skins black and they are now the African negroes.

Another stream of the yellow-brown first men of Asia migrated northward and northwestward into northern Europe. Here the climate was cold and cloudy. There was very little sun; sometimes none at all for days at a time. Gradually the brown and yellow pigments of the skin faded. The hair and eyes were similarly bleached. Thus, scientists believe, arose the blonds.

These changes in the skin and eyes and hair were accompanied, the experts feel certain, by changes in temperaments and emotions. An example has been traced in detail by Professor Huntington. It is the instance of the American Indians.

This red race of North America came originally, anthropologists believe, from Central Asia. In the course of thousands of years the original American Indians migrated slowly northward and eastward through the plains of Siberia until they came to the narrow gap of Bering Straits which separates Asia and North America. This gap was easy to cross. Within a few centuries the original American Indians were settled in North America and were sweeping southward to occupy it.

The important part of this history, Professor Huntington believes, is the long residence of the

Indian race in the cold and desolate lands of Siberia and Alaska. Here the race was exposed to enormous hardship. In Siberia there now exists, Professor Huntington records, a nervous condition called "Arctic hysteria." The victim of this disorder virtually goes crazy, runs away into the wilds, ultimately is apt to commit suicide. The condition is almost certainly caused by the strain and distress of living long months at a time amid the cold and darkness and privation of the northern winter.

It is well known that the average Indian is stoical, less apt than any living race to display what is called a "nervous temperament." The explanation, Professor Huntington says, is simple. All the individuals of the original Indian race who had the least tendency to over-nervousness or emotionalism went crazy or died during that thousand-year-long journey which the race made from Asia around through the Arctic snows to North America.

A similar set of circumstances explains, Dr. Woodruff and others have urged, existing differences in temperament between European blonds and European brunets. For thousands of years the blond races have lived in northern Europe, where the climate is perhaps less severe than in northern Asia and Alaska but is still severe enough to leave its mark on any race that faces it for many centuries. Optimism, for example, is a necessary trait of the successful dweller in the northern lands of long winters; as is also the tenacious, far-sighted practicality now so characteristic of the blond racial strains.

If there chanced to be among a tribe of blond Scandinavians thirty or forty centuries ago one family composed of people who took no forethought

for the future and stored no food for the winter, that family would die of starvation before the six-month reign of ice and snow had passed. Of if any one grew hopeless and despairing, will would be lacking to survive the long months of dark and cold. Thus tenacity and optimism were encouraged and bred into the blond race; carelessness and thoughtlessness were bred out.

In sunny Greece or Italy, on the other hand, no man needed to work hard for food. Shelter was scarcely necessary at all. Foresight was useless. There was time to think and to imagine. Thus may have arisen, the experts believe, the characteristic traits of the black-haired, black-eyed men and women of the south.

In his interesting essay on "The Comparative Abilities of the Fair and the Dark," the distinguished British psychologist, Dr. Havelock Ellis, records his study of the complexions of famous Britishers whose portraits are preserved in the National Gallery in London. The political reformers, the soldiers, the sailors, the men of science, he found prevailingly blond. These are occupations requiring, he points out, unusual foresight, determination and optimism. On the other hand the actors and actresses, whose occupations require easy display of emotions, were found to be prevailingly dark.

In America, racial conditions are too new, the experts agree, for any equilibrium to have been established between the people and the climate. On the whole, Dr. Woodruff thinks, America is suitable for darker complexioned people than now occupy it. The present American population is too blond, too optimistic and practical, too little emotional, for the

climate that America provides. If so, there will probably be a change. There seems already evident, some observers of American life have been inclined to believe, a tendency toward emotionalism and easier emotional display. Perhaps this is the first step in the climatic transformation of America's character; a sign that America's emotions, no less than its people, are becoming more brunet.

Climatic influences other than those of light are thought, also, to cause some racial differences such as those between negroes and whites. The negro nose, low and flat, is open and direct in its internal structure. The white nose, comparatively longer and thinner, has a more convoluted interior. It is a reasonable assumption that the negro nose has been evolved to suit a hot, moist climate and the white nose a climate colder and dryer. Breathing through a negro nose is easier than through a white one and more heat may be lost through it. Like tropical animals, the negro's breath is discharged from his nostrils hotter. The white nose, on the other hand, is a warming and moistening organ. Incoming air is warmed and wetted before it reaches the lungs, a procedure unnecessary in the tropical habitat of the negro. Also, the air leaving the lungs through the white nose is cooled before it escapes. The white nose is therefore a device for conserving body heat.

The suitability of negro noses for warm, moist climates but not for cold, dry ones is held responsible for the fact that negroes living in northern countries suffer from pneumonia, pulmonary tuberculosis and other diseases of the breathing apparatus to a much greater extent than do whites. For an opposite reason, the handicap of the long, thin nose is one of the

reasons why whites do not do well in the tropics. It is probably quite true, although nobody seems to have collected statistics, that the whites with the thinnest noses are less apt to live comfortably in hot, moist lands than are those whose noses are broad, thick and almost negroid.

As an example of the possibilities of climatic effects on health and habits, Professor E. A. Vuilleumier has suggested, perhaps humorously, that why the men of Arizona are notoriously silent is that their climate is so dry they cannot open their mouths without parching their throats! The corollary suggestion that members of Congress are garrulous because the climate of Washington is so damp seems not to have been offered. Perhaps an air dryer in the Capitol would help; the possibility of an air cooler in such surroundings is open to question.

Even the strong, silent men of Arizona, if their race survives long enough, will no doubt develop breathing apparatus that can accommodate dry, hot air to their throat and lungs. But that may take a long time. This question of time is also pertinent to the long-standing arguments about whether white people can live permanently in the real tropics. The weight of scientific opinion is that they can if they adjust their clothing, diet and habits to conditions proper for tropical life, but it is probable that this conclusion is a safe one only for a proportion of the population. Some individuals seem able to retain health and energy in the tropics while others cannot. It is uncertain, of course, why these individual differences exist but probably they begin, as do so many other relations between climate and health, with the varying degrees in which individuals can tolerate ex-

cessive ultraviolet light and extremes of loss of body heat.

Other phases of weather which are known to have such important effects on health that they may change racial characteristics are those due to altitude. Life in high mountains alters the character of the blood, the chest expands and other bodily changes take place. These are examples of the adaptability of the human organism. They are compensations arranged by Nature to offset the decreased density of the air and the corresponding decrease in the supply of oxygen.

Less certainly related to direct climatic influences are the effects of weather visible in the mortality statistics. Even aside from Professor Huntington's figures already quoted, there can be no doubt that the number of deaths per week or per hour is influenced by the weather but this may not be a direct effect. The exact instant of death is apt to be determined by extra strain, depression, or excitement imposed by external circumstances but such nervous complications themselves are often traceable to weather. The Scientific American once made a study of the hours at which people die. All the natural deaths in New York City during 1923—some 25,000—were tabulated hour by hour and a curve was plotted.

The first thing of importance which this curve showed was that the average number of deaths is different at different hours. The greatest number occur between one A.M. and six A.M. Midnight, the traditional dread hour, was found to be the hour at which fewest people die! Next to midnight in infrequency of deaths was noon. So far as these figures

meant anything at all it was decided that most people die after meal times. The hours where the curve was lowest are those just before people are usually fed in hospitals. The reason seems to be that expectation of something interesting about to happen keeps the vital spark flickering until that happening is over. Then the let-down brings death. Much this kind of indirect psychological influence is apt to apply to the effects of weather on death.

Still different and still mysterious are the indubitable effects of weather on epidemics of disease. Both the number of cases and the number of deaths in an epidemic seem to have relations to changes in weather. Certain epidemics, notably those of influenza, unquestionably recur periodically but at no known regular interval. For influenza 15 to 30 years seems about the rule. It is possible that this recurrence of epidemics could be traced to weather cycles, but once more, there has been little attempt to run down this clue.

Certain individuals, mostly the old and the ill, are able to predict some weather changes by their bodily symptoms. Rheumatism for example, often becomes extra troublesome when a storm impends. It is futile to deny the reality of such weather symptoms. Yet no one has any idea of how they work. The physician who seems to have given this problem the most study is Dr. A. Dias of Rio de Janeiro. He concludes that the bodily effects of impending weather are probably caused by variations in the external stimulation of the body—stimulations due to changes in heat, perhaps also to changes in air pressure. These variations in stimulation affect the unconscious part of the nervous system, he thinks,

and thus the activity of the glands, since these organs are probably interrelated. His conclusions are plausible but cannot be taken as proved.

Which is a statement applicable to most of what little is suspected about the influences of weather on health. There most surely are such influences, but what they are and how they work are guesses not yet able to stand the tests that science asks of its facts.

Chapter 27

WALL STREET WEATHER

THE business man seems recently to have taken to his bosom certain branches of knowledge which a few years ago, in his then rôle of tough, horse-sensed average citizen, he would have considered long-haired and effete. Doubtless his new part of patron of the arts and sciences was thrust on him by the development of advertising, that somber game of making many words out of few ideas. Advertising has draped about commerce a gaudy mantle of dignity and romance and learning, and business men have been trying to live up to their uniforms ever since. This view is strengthened by the gamey smell clinging to so much of the "science" which business plays with—the memory courses and will courses and character analysis courses and all the other doubtful adaptations of alleged psychology. Business, at any rate, is "sold" on science, genuine or spurious, and is alert for any new utility to which science may be put.

Which makes the outlook hopeful for an application of psychology that would be far from difficult to evolve and which might have a practical value far exceeding that of the hokum psychologies even if the latter were sound. This is the psychology of weather; the study of the possible effects of weather on the human mind. The existence and the importance of such effects are so commonly admitted that it seems strange to find weather psychology a neg-

lected factor in business, especially in buying and selling.

As a science, the thing is not yet born. There is nothing known about root causes and end effects. There is merely an admission that the problem exists and a realization that it can be attacked by scientific methods.

There can be, and there is, "buyer's weather" and "seller's weather." The problem is to find out which is which.

Every business man knows which are the seasonal businesses and how they are affected by weather conditions. The cold spring of 1927 played hob with the straw hat business. The damage was not repaired by the warmth of August and September. One warm winter will do for many firms in the fur business. A rainy summer often annihilates amusement parks, summer hotels, summer resorts. Purchases of one variety or another of fabrics for women's clothes, although based on the still more erratic whims of fashion, are affected largely by the nature of the year's weather. The business done in a single day by theatres and restaurants is radically altered by weather changes. These effects of weather on businesses are perfectly well known.

There are equally well known effects which concern larger businesses such as agriculture, railroads and finance. Banks watch the weather as closely as any scientist could, for it is said that the course of prices, international exchange and other variables of the banking business can be predicted from records of world weather alone with more accuracy than if all other factors were taken into account and weather neglected. Weather, in matters of large finance is

not only the greatest single factor; it is larger than all other factors put together. Of course, the forecaster of these effects of weather on prices must be something of a prophet, so complicated are the factors and their interrelations.

Well understood as are these direct influences of weather on business it happens all too often that the understanding comes too late for individual businesses to do anything about it. Thus, the business of the British Syphon Company, manufacturers of the soda water which combines so pleasantly with whisky against the British palate, fell off badly during the cold, rainy summer of 1927—so badly that whereas those should be the briskest months in the soda water calendar they were really the slackest. But not until the Company's annual meeting in December was the cause of the bad news broadcast to a palpitant world.

During the winter of 1927-28 and through the following spring hundreds of substitute teachers in the public school system of New York City complained that they had virtually no employment and were suffering real financial distress. There had been abnormally few calls for substitutes. Nor was there an excess number of substitutes among whom to distribute the calls. The reason given at that time for the slackened need for these extras was the mild weather of the winter. Fewer of the regular teachers took sick. It is possible that the mild winter really was the chief cause of this pleasant catastrophe, but it is equally possible that the recognized improvement in the general health of the community had something to do with it.

It is true that even if the British Syphon Company and the New York substitute teachers had foreseen

the coming of slack months, there was nothing much they could have done about it. But the soda water manufacturers might have restricted their production and the teachers might have got jobs in other businesses; which, in a manner of speaking, would have been doing a great deal about it and might have saved them money.

Organizations that hold conventions are taking cognizance of weather forecasting and are also more and more given to consulting weather records before deciding on the dates of meetings. By so doing they give themselves the advantage of the odds, but the advantage is none too great, for neither records nor forecasts can insure that the convention parade will not be rained on.

But none of these effects of weather on business, not even its probable effects on the price of bonds is as important as that which works through psychology. This comes back to the "buyer's weather" and its opposite of "seller's weather."

Psychology, it is now admitted by all students of business, plays an extremely important part in assembling the various factors collectively called "prosperity." The prices of securities and commodities, the amount of buying done by the public, the advance orders placed by manufacturers, the decisions of big industries to increase or curtail their production—all the ripples that make the ebb and flood of business tides for a year or a decade—are founded somehow on psychology. The "feeling" of the market, no matter how caused, is one of the chief determinants of the whole state of business. Apprehension or assurance, optimism or pessimism; these psychological states pull the strings of business all over the world.

Any person knows that his moods vary from time to time and that his mood is more often than not dependent on nothing tangible. There are times when he is optimistic, easily approached, easily convinced, for no good reason that he can discover. It is very probable that this mood is not confined to him alone but that there is a wave of optimism and ease and good feeling all over his neighborhood and perhaps over the whole country at the same time.

Such a day, when "sales resistance" is low, is a seller's day. Even a poor salesman can sell anybody anything, on seller's day.

But when the mood changes and pessimism succeeds optimism, then it becomes "buyer's day." The person who bought a carload of lace bathtubs on seller's day loses his geniality and his gullibility, becomes critical, loth to commit himself, impossible to "sell." He will buy with skill and judgment on buyer's days, but if he manages to sell anything he will sell it too cheap, for he himself will have become doubtful of its value.

If there are such things as country-wide seller's days and buyer's days, whether caused by weather or by something else, the seller's day will be one when everybody feels optimistic. Salesmen will ask high prices and get them; both parties to the transaction will have, temporarily, an exaggerated idea of the value of the goods, of the prospects for the future, and of each other's merits as good fellows and sound business men. The profit of transactions on such days will run chiefly to the seller.

But on buyer's days the profits will be his and losses will be mainly the seller's. Pessimism will lower even the "asking price." Buyers will be so un-

willing to buy that only very real concessions can move them. What bargains are struck will favor the buyer.

The canny business man will attempt, of course, to reverse these tendencies of his moods. When he feels chipper and regards the world as none too bad a place after all—then is the time to go out and unload a ton of monogrammed penwipers on the purchasing agent of the Peruvian Navy. Also it is the time to be "in conference" to any and all salesmen, for it is a seller's day and nothing one buys will be a bargain. But when the world sours and he views the sunlight and puppy dogs and children at play with loathing and disgust, let him then take up his scrip and tread the market places with hospitable mien, for nobody can sell him anything at prices above mere cost and the discounts offered for cash will be amazing. Man should buy, then, on a buyer's day, but his salesmen should have the day off, for through their bilious eyes anything they can get will satisfy them and their sales will ruin their employer.

This matter of waves of buying and selling psychology is quite well understood in such concentrated market communities as Wall Street. The experienced keepers of that particular gambling house know well that the psychology of the market sometimes favors bulls and sometimes bears. They know, too, that such psychological states are apt to affect the whole trading public at the same time.

But it has not been realized so thoroughly that business in general follows the fancy of such moods, nor is it even suspected in many quarters that the chief element of cause is probably the weather. There are no facts to prove this contention, but that

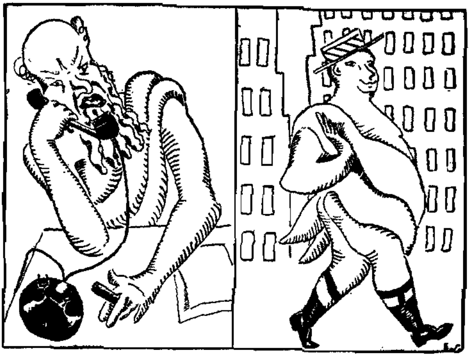
lack does not disprove it, either. As Potash and Perlmutter said about the two-year-old note: "We don't positively know it's bad."

One thing is certain: The weather affects psychology. Just how or why nobody knows. Telephone operators, hotel clerks, railroad employees and others who come in contact with the public know all too well that there are days when everybody is impatient, disagreeable and snappy. Other days the same public is courteous, reasonable and pleasant. Nobody knows why, but most people blame the weather, and probably with justice.

The weather, naturally, cannot be the only factor affecting the swings of business even where it concerns individuals. There will always be those who do not respond to the weather or whose state of mind on any particular day is determined more emphatically by temporary ill health or by personal fortunes or other individual things. Certain definite causes other than weather affect mass psychology in business also, as witness the market explosion that followed the mysterious disappearance of Captain Lowenstein in July, 1928.

But in any analysis of the whole state of business, the effects of the weather on the psychology of the business public should bulk large if for no other reason than because so many of the individual factors *not* related to the weather will oppose and cancel each other. It is a field inviting to the commercial economist, this relation of weather psychology to business, for no one has yet ventured beyond the vague and sketchy outlines which are here explained.

If it should prove true, as the present authors believe, that a definite enough connection can be traced



IS IT WEATHER MAKES THE WORLD LOOK WRONG OR RIGHT?

When you feel like the gentleman on the left you may buy things but not sell them. But when your mood changes to that of the optimist on the right then is the time to do your selling and forget to buy. "Buyer's weather" and "seller's weather" probably fix more losses and more profits than most business men are aware.

between the state of the weather and the state of mind of business, then the next thing to find out is what kinds of weather make for what kinds of mind. This done, forecasts from that new point of view will become the most important thing in weather science—infinitely more important than predictions of rain or cold. It is by no means fantastic to imagine that the Weather Bureau will one day include in its forecasts the warning that the next twenty-four hours will be buyer's weather, to be followed by three days of fair and warmer seller's weather. The Bureau could do worse.

Chapter 28

WHAT TO DO

WHEN people ask if man will ever be able to control the weather they mean: Will man ever be able to turn on rain, snow, hail, sleet, cold, heat, fog, wherever and whenever he wishes, and turn them off when he has had enough? Will he be able to stop a storm in its tracks, to thrust aside ocean currents, to throttle the winds, erase the lightning and banish the clouds? They mean all that by their question and the answer is No. Man may be able to do some of these things some day, but he is unlikely to achieve all of them and unless he can do all of them he will not "control" the weather in that common meaning of the word.

But if the word is used in another and truer sense control of the weather is already an accomplished fact.

Man cannot impose his will on any force of Nature. What he can do is to persuade the forces to act according to his preference, to turn them to account, as he has done with electricity. Man's success in the world has been won by fitting human ideas and necessities into the principles of Nature, not by attempting to alter the principles. The other idea has an ancient history but one of failure.

The idea of rainmaking probably began with the hoary belief that rain usually follows a battle. Even before the introduction of gunpowder this belief

existed, the storms being ascribed to some magic effect of victory or defeat. When gunpowder came into use the idea of cause was shifted and it was said that explosions brought on the rain. In popular reasoning this led to the idea that loud noises made the clouds condense and the drops to fall.

The most comprehensive group of experiments ever attempted on this subject were made in the '80's by the United States Government under the direction of General Robert Dyrenforth. Cannons were fired at the sky. Balloons carrying charges of explosive were sent high in the air and exploded.

Nothing happened. Sometimes it rained after the explosions, sometimes it didn't. No evidence whatsoever was obtained which would indicate that noises or explosions produce rain.

Nevertheless, such methods of rain-making persist. And in France cannons are fired at hailstorms.

There is, of course, something at the bottom of the rain-after-battle idea. There is always some reasonable basis for a popular belief long and widely held. In this case the explanation is simple. Commanding generals, who fix the dates of nine battles out of ten, usually wait for good weather before conducting the troop movements which precede the engagement. Such troop movements usually require three or four days. If rain intervenes the movements are held up and the battle is postponed. It happens, therefore, that preceding the majority of military engagements, ancient or modern, there has been a period of three days to a week of clear, unrainy weather.

It also happens to be a characteristic of North America and Europe that the weather changes at

intervals of three days to a week. Very seldom on either continent does good weather last longer than five or six days at a time. It is almost mathematically certain, therefore, that rain will fall within a day or two after the end of the average battle. The battle has nothing to do with the weather; the weather merely fixes the date of the battle.

A surprisingly large part of the population still pays money, however, to have rain made for it, and pays it gladly because rain quite often falls even before the money is paid. The western states have been favored for some years by the efforts of gentlemen who take "rain contracts." One of these individuals goes into a farming district and receives payment only if a certain amount of rain falls. A most equitable agreement, certainly. The farmers need rain and their peace of mind is worth paying for, even if it would rain anyway.

The rainmaker's idea is quite simple. He knows the average rainfall for the district. He may even know something of average weather cycles. And he sets the limit of rain which he proposes to produce below the average that is to be expected. Occasionally he fails but more often the rainfall is greater than the limit he has set. His profits must be tremendous in percentage for the "secret apparatus" is usually contained in a small windowless house from which emerges nothing but a little smoke producible by a few cents' worth of oil or camphor. The rainmaker is merely betting on averages, just as life insurance companies bet on the mortality averages. Like the "house percentage" of a roulette wheel, the drag of rain averages favors him. The oftener he gambles the greater is his percentage of success.

Somewhat greater scientific plausibility accompanies the suggestion that the climate of desert regions, notably parts of South Africa, could be changed by creating artificial lakes. It has been urged for this reason that the Sahara be flooded with sea water, and that Death Valley, which lies below sea level in California, be converted similarly into a sea. The idea is that such water areas would serve to produce additional rainfall. It happens, however, that Nature has already made such an experiment which man was able to observe.

Early in the present century the Colorado River broke through the headgates of the irrigation system in the Imperial Valley, on the border between Mexico and California, and flowed for many months into the Salton Sink, which was then dry. This flood created the Salton Sea, a portion of which still exists. Seizing the opportunity for testing many tentative theories, the United States Weather Bureau set up an observation station on the shore of this Salton Sea. Records were made of rainfall, temperature, humidity, and also of the rate of evaporation of water from the surface of the lake and from pans placed at various distances from the shore.

The results were conclusive. Such bodies of water do not affect materially the climate in their neighborhood. Two hundred yards back from the Salton Sea its effects on the weather were nil. The rainfall of the region was not altered in the least. Bodies of water covering even thousands of square miles are too small to mean anything to weather.

In 1926 Professor Paul Painlevé, one of the world's most distinguished mathematicians and then French Minister of War, suggested that something

could be done about rain by means of radio waves. The idea is sound to this extent: the nuclei around which raindrops collect are often electrified atoms or other electrified particles. Radio waves certainly affect these particles. Conceivably this might influence the weather.

But the verdict of science is against Professor Painlevé's idea for two reasons. The first is that the essential element in producing rain is not the initial condensation on the electric nuclei but the subsequent vertical circulation of the atmosphere which enlarges the minute cloud drops until they become rain drops. The second adverse argument is that it would take too much radio. Calculations show that to add by means of radio enough energy to the air to have any worth-while effect on its electric nuclei would require millions of times as much power as any present radio station can emit.

Coming then to the other kind of "control" that man can have over Nature, the way in which man handles electricity is a case in point. Man cannot control electricity in the sense that he forces it to do anything. Instead, when an electrical engineer wishes to make electricity flow from one point to another he provides for it a path which it prefers; a wire of material that will conduct the electricity. He humors the electric particles by suiting his own requirements to their habits. Occasionally, of course, man does something that electricity does not like. Then something "burns out" and it is said that electricity has "escaped control."

It did not escape control because it never was under control. What happened was that man tried to control it and trouble resulted.

Precisely these same principles have been applied by man to his conquest of weather. He has discovered what weather likes to do and has adjusted himself or his circumstances to suit the weather's preferences. Houses once were blown away by every brisk wind. Man could not prevent winds, but thousands of years ago he solved the problem by building houses which the wind would let alone. As for rain, man has devised for it the two greatest systems of weather control—roofs and umbrellas. He has not prevented or even hindered rain. But he has made it comparatively unimportant to his person by suiting his equipment to its habits.

In the same way he has managed to control heat. Clothes are part of the system. Their effect is to make the body relatively immune to changes of temperature. True, the purpose of clothes has got mixed up with a lot of ideas about adornment, sexual attraction and modesty, and as a result complete control of the weather's heat by this means is made impossible. In the United States, for example, the ideal summer clothing would be a single loose garment like the Roman toga. The only possible arguments against the wearing of such a garment are based on habit and foolishness; unless one considers mosquitoes an argument.

Any number of commonplace things are designed primarily for purpose of weather control. Rubber overshoes are one item; raincoats, automobile tops, windshields, electric fans, refrigerating systems, steam heat and others. All are adaptations of man's habits or surroundings to the habits of the weather. Only by such compromises has man ever gained "control" of any natural force.

And, with certain conceivable exceptions, it seems indubitable that only by further compromises will he be able to extend his control. Obviously the need is for better understanding of such forces as those which make weather, in order that compromises may be more finely adjusted. It is commonly said that the aim of weather science should be directed at long-range forecasting, so that the general character of the weather may be known months or years before it arrives. There is, of course, a real need for such super-prediction, but it is only one of many needs and not necessarily the prime one. So far as man and weather are concerned, a greater need is the better understanding of details of how weather works. With such intimate knowledge might come not only the desired long-range forecasting but many more possibilities of human adjustment than are now conceived.

Such possible adjustments cannot even be imagined, in the present state of comparative ignorance about the mechanisms of weather. But neither could radio have been foretold when "galvanic" batteries were the last work in "electromagnetism." The untamable force of electricity was there then, as it has been there and everywhere since there was a universe and will be there, as unconquerable as ever, when present day radio shall have become as clumsy and outmoded as a matchlock. It was only when man learned the intimate details of electric force that he was able to make livable compromises with it.

Willy-nilly, man lives surrounded by the cogs and wheels of the great weather engine driven by the sun. To the extent that he understands these cogs and wheels is he able to live comfortably among

them, for only by understanding the weather is he able to escape the stigma of Mark Twain's observation. Only by adjusting himself to what the weather wants is man able to do anything about it.

Other Books

METEOROLOGY: THE SCIENCE OF THE ATMOSPHERE, by Mr. Charles Fitzhugh Talman of the United States Weather Bureau. Published as volume 1 of the Popular Science Library edited by Garrett P. Service, *P. F. Collier and Son Co.*, New York, 1922, 384 pages; also as a reprint separate from the Library by *Reynolds Publishing Co.*, New York, 1925. A readable, correct and comprehensive general book; the best book to read next if this one has interested you.

PHYSICS OF THE AIR, by Dr. W. J. Humphreys of the United States Weather Bureau. *The Franklin Institute*, Philadelphia, 1920, 656 pages. The foremost professional treatise on what is known about the workings of the weather. A new edition is in preparation (1928) by the *McGraw-Hill Book Company*, New York.

MANUAL OF METEOROLOGY, by Sir Napier Shaw. *Cambridge University Press*, Cambridge, England, or *Macmillan*, New York, 1927 and 1928, 2 volumes, 339 pages and 445 pages. The best all-round text book on meteorology but keyed largely to conditions in Europe instead of America.

METEOROLOGICAL OBSERVER'S HANDBOOK, compiled and issued by the British Meteorological Office, sold by *His Majesty's Stationery Office*, London. An edition was issued in 1926. The best set of instructions for amateur weather observers.

World Weather Records, collected by H. Helm Clayton. *The Smithsonian Institution*, Washington, D. C., 1927, 1199 pages. The most complete and accurate collection of weather records ever compiled.

Climate Through the Ages, by C. E. P. Brooks. *Ernest Benn, Ltd.*, London, 1926, 432 pages. The most recent, as well as the most readable, account of the ebb and flow of world weather in past centuries, with some speculations about the causes.

Man and Weather, by Professor Alexander McAdie. *Harvard University Press*, 1926, 99 pages. An interesting account of a few selected high-lights of weather's influence on human affairs.

Weather Influences, by Professor Edwin Grant Dexter, *Macmillan*, New York, 1904, 281 pages. The only book devoted to effects of weather on crime, community health and other social matters; empirical, out of date and badly needing revision, but highly stimulating to one's curiosity.

Medical Ethnology, by Charles E. Woodruff, M. D.; *Medical Art Agency*, New York, 1915, 307 pages. A stimulating argument for the profound effects of sunlight and other climatic elements on human races, but not always to be taken as Gospel.

The latest presentations of Professor Huntington's ideas about climate and civilization are in The Pulse of Progress by Ellsworth Huntington, *Charles Scribner's Sons*, New York, 1926, 324 pages; and The Human Habitat, by Ellsworth Huntington, *D. Van Nostrand Co., Inc.*, New York, 1927, 280 pages.

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